A TECHNICAL JOURNAL FOR DESIGNERS AND USERS OF ELECTRICAL, ELECTRONIC, HYDRAULIC, MECHANICAL AND PNEUMATIC CONTROL SYSTEMS AND INSTRUMENTATION

CONTROL

SYSTEMS · INSTRUMENTATION · DATA PROCESSING · ENGINEERING · APPLICATIONS

VOL 2 NO 11 MAY 1959

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LOOKING FOR A JOB? CONTROL *carries the best jobs going in instrument and control engineering.* **SEE PAGE 152 AND ONWARDS**

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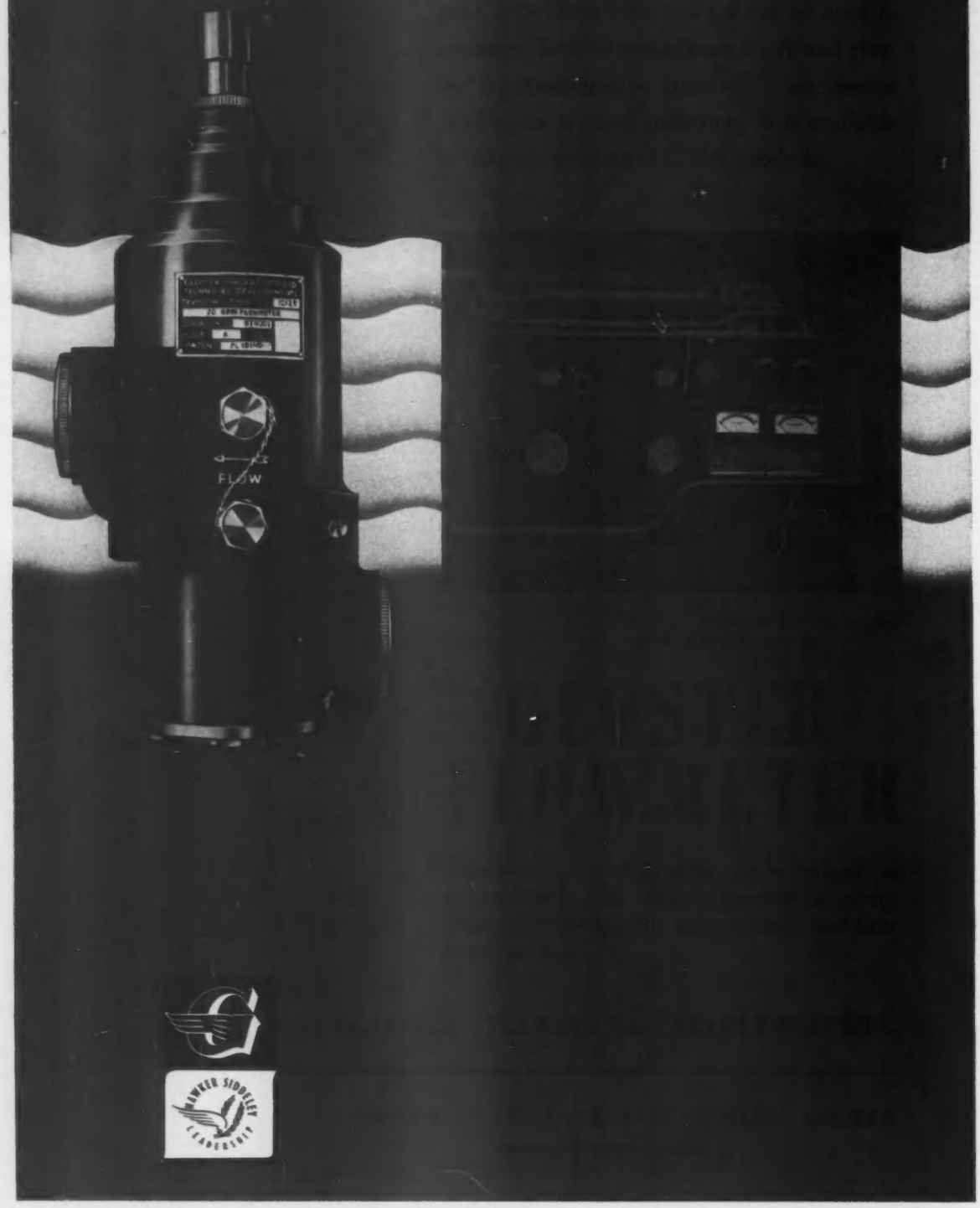

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CONTROL

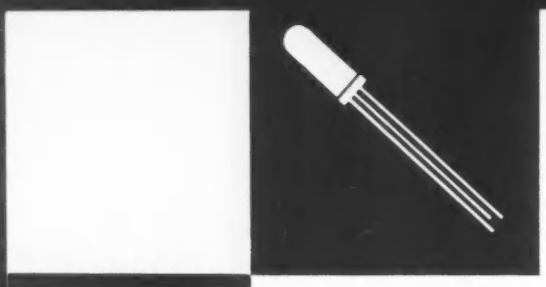
PUBLISHERS COLUMN

BEYOND OUR CONTROL

As we write, the dispute in the printing industry—already interfering with production of CONTROL—moves to a head. Publishers clearly face a period of upset and uncertainty. We apologize to you now for any future delays in publication that may come from causes we cannot control. But we trust that this issue at any rate will be safely printed by the time the result of the printing unions' ballot causes further action.

Here we naturally do not want to say anything to aggravate the dispute. As a publishing house, we are quite independent of any printing firm and we certainly do not take sides between management and men. All we would do is to repeat the truism that in the end this dispute—like other industrial disputes—will have to be settled by talking. Both management and men will be losers if either side adopts practices that reduce turnover *before* the talking begins. Profits and wages lost during lock-outs, strikes or short-time working take many months to be recovered—if they ever are. And not all the printing work that goes to the Continent during an emergency returns when the emergency is over.

This month we have, quite independently of the printing dispute, changed our printer for CONTROL to The Haycock Press, who have for many months printed our successful sister magazine, NUCLEAR POWER. The firm has been most helpful in making this change as smooth as possible at a difficult time. But partial restriction on overtime working has inevitably had its effect, and our Production Manager's schedules have been operating like British Railways' timetables last winter. Thus we believe you will excuse us if parts of this issue are not up to the visual standard you have rightly come to expect in CONTROL. May there be a rapid settlement of the dispute, fair to each side; then with our new printers we shall strive to offer you each month an even better produced CONTROL than before.



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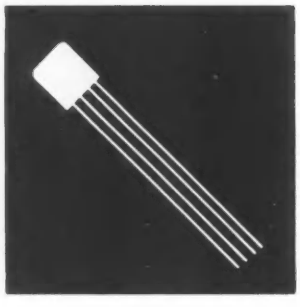

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Germanium alloy transistors
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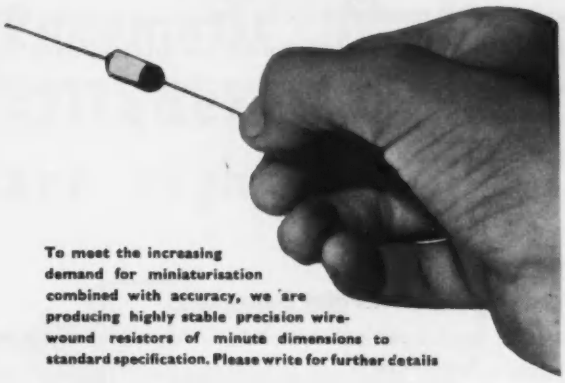

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Sir!

The Editor welcomes correspondence for publication.

National Control School

SIR : The leader in your March issue called for the establishment of a National Control School. This article was most timely and it is to be hoped that it will give rise to discussion of the subject and possibly to some action. I think, however, that you rely too heavily on the analogy of the Harwell Reactor School and demand too much of the Government and too little of industry.

At the time the Reactor School was set up, skill in nuclear engineering was concentrated in one or two establishments and it was obvious that if more engineers were to be trained quickly, this could only be done at Harwell, using the existing staff and equipment. Furthermore, the UKAEA have always had more freedom of action than is possible for Government departments, which are directly responsible to Parliament. If the Government showed favour to one technology, other organizations would press for like treatment. A better analogy is the College of Aeronautics. This, however, was set up to serve one industry at the end of the war, when its future was in great doubt (as it so often seems to be). But I understand that the continuing support by the Ministry of Education has been contingent on substantial contributions made by the aircraft industry.

Industry must help

I have had some experience in organizing postgraduate courses on such subjects as electronics, servos, production engineering and process control. I have found the Ministry of Education to be most sympathetic over the aims of these courses and not ungenerous within the tight limits set by the traditional pattern of expenditure. But technical colleges cannot do very much without the help of industry. This applies particularly to the supply of men of considerably more than average ability to train. It is our experience, and, I think, that of others, that men profit most from postgraduate courses if they have worked in a team for a few years after taking their first degree. By this time they will have a reasonable income and may well be married or thinking of marriage. Few are willing to return to the standard of living possible on a bursary. Most students must therefore be sponsored by a firm, and this at a time when, if they are of the required calibre, they have become useful. With a few exceptions, the record of firms in making such short-term sacrifices is poor. This, then, is one way in which industry can help.

A second way for industry to help is by providing equipment and, particularly, examples of the applications of control techniques. A third and most important way is by financial support for the research without which no academic organizations can remain healthy.

To sum up, I agree with your general thesis that a focal point for control engineering is needed, but have little hope that it can be provided quickly, and think that, for instance, the Engineering Industries' Association should devote much of its effort to convincing its member firms.

'DON SERVO'

Cambridge, Cranfield and London

SIR : I wonder if you could tell me whether there are any full-time postgraduate courses in control engineering, apart from the Cambridge course noted in your April issue, that are due to be held this year.

Southport C. G. LLOYD

●*The only other full-time postgraduate courses specifically on control engineering that we know will be held next year are at Imperial College, London University;*

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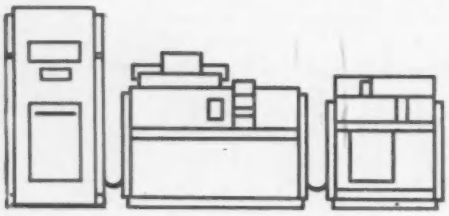

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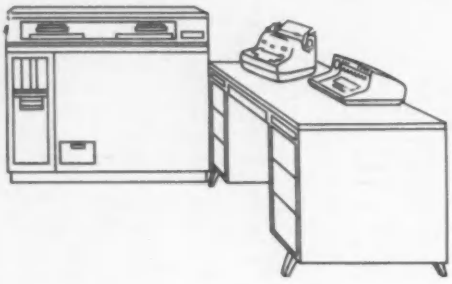

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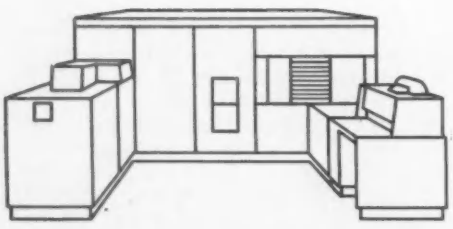

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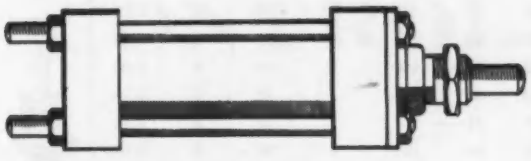

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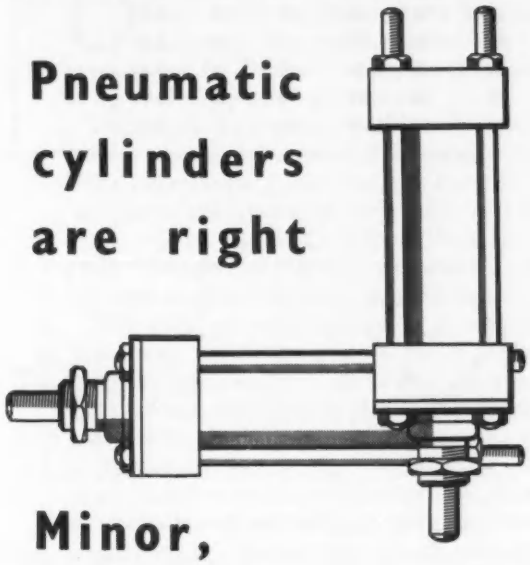

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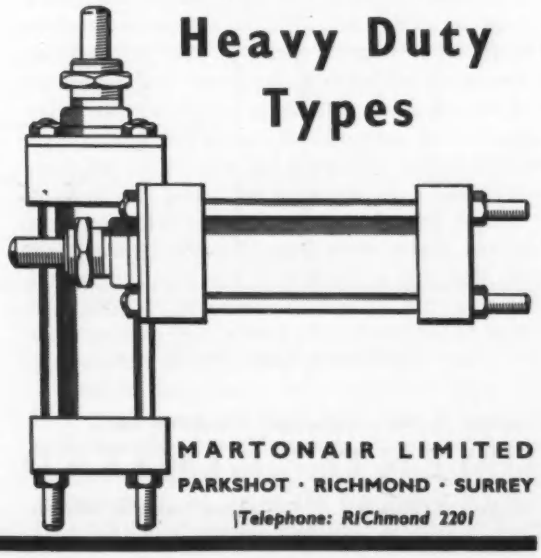

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Continued from page 63

Sir!

Battersea College of Advanced Technology; and the College of Aeronautics, Cranfield. Each of these starts in the autumn and lasts upwards of a year.

You may also be interested in the postgraduate course on information engineering, at Birmingham University. This comprises a good deal of instruction on automatic control, computers, etc. A postgraduate course at Edinburgh University also includes some automatic control. As you no doubt know, many technical colleges run brief full-time courses in aspects of control engineering such as servo theory, instrumentation, telemetering, etc.—EDITOR.

Wrong missile jargon?

SIR : I refer to my letter published in last month's CONTROL, in which I pointed out that certain explanations given in the list of missile terms in the March issue are at variance with the officially agreed definitions.

It would be embarrasing to the Ministry of Supply if definitions of terms are published which are different from those which have been already agreed between the Ministry, the Services and industry and I shall be glad if you will publish the following list of agreed terms and definitions relating to those previously appearing in CONTROL.

Control surface	A movable aerofoil attached to a missile body to change the attitude of the missile in flight.
Attitude	The inclination of the axis of a body to a fixed axis system.
Wing	A fixed or movable aerofoil attached to a missile body. Its main function is to supply lift.
Fin	A fixed aerofoil attached to a missile. Its main function is to supply stability.
Missile body	That part of a guided missile to which the wings, fins, control surfaces and boosts are attached to form a complete missile.
Rocket motor	A non-airbreathing reaction propulsion device that consists essentially of a combustion chamber(s) and exhaust nozzle(s) and a solid propellant charge from which hot gases are generated by combustion and expanded through the nozzle(s).
Rocket engine	A non-airbreathing reaction propulsion device that consists essentially of an injector, combustion chamber(s) and exhaust nozzle(s) and utilizes liquid fuels and oxidizers from which hot gases are generated by combustion and expanded through the nozzle(s).
Boost rocket motor	A rocket motor for accelerating a missile. For an item complete with nose, fins and/or other fittings, use the term *boost rocket motor assembly*.
Integral boost	A boost rocket motor assembly which does not separate from the missile.
Tandem boost	A boost rocket motor assembly which is located at the rear of, and is coaxial with, the missile.
Wrap-round boosts	A number of boost rocket motor assemblies located externally along the sides of a missile body.
Sustainer rocket motor	A rocket motor which continues to provide thrust after the boosts, if any, are all burnt and which does not separate from the missile. For an item complete with fittings use the term *sustainer rocket motor assembly*.

Pioneer Designs Ltd. M. D. HULL

●*We are happy to do this. And we should hate to embarrass the Ministry of Supply (is it really 'embarrassable'?). But surely the Ministry could escape from its quandary by publishing the completed parts of its glossary.*EDITOR.

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1S501	22	150	4	10	8	0.08
1S502	24	150	4	10	8	0.08
1S503	27	150	4	10	8	0.08
1S504	30	150	5	10	8	0.08
1S505	33	150	5	10	8	0.08
1S506	36	150	6	10	8	0.09
1S507	39	150	6	10	8	0.09
1S508	43	100	7	10	8	0.09
1S509	47	100	8	10	8	0.09
1S510	51	100	10	10	8	0.10
1S511	56	100	11	10	8	0.10
1S512	62	50	14	10	8	0.10
1S513	68	50	16	10	8	0.10
1S514	75	50	24	10	8	0.11
1S515	82	50	26	10	8	0.11
1S516	91	50	40	10	8	0.12

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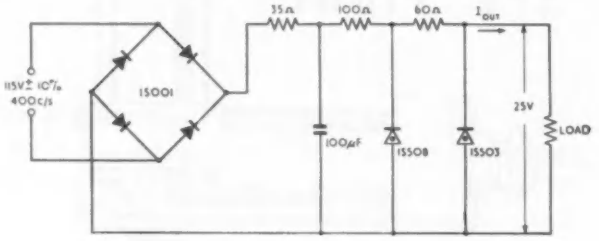

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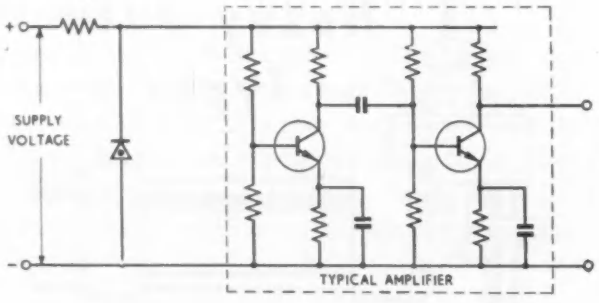

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CONTROL

MAY 1959 VOL 2 NO 11

Transistors take over

OPERATIONAL LIFETIMES AS LONG AS TEN years are being hazarded for the newer transistors; this only ten years after their development by Bardeen, Brattain and Shockley at the Bell Telephone Laboratories.

This month the transistor will be the subject of intense professional interest. The occasion is the IEE's International Convention and Exhibition on Transistors and Associated Semiconductor Devices, which will be held at Earls Court from May 21 to 27. In honour of this important event CONTROL has a pronounced transistor bias this month.

Both users and manufacturers of transistors are now giving the device a clean bill of health in many applications. For instruments the trend is quite definite: most makers of industrial electronic instruments are changing from thermionic valves to transistors. Why is this? Probably, as several of our contributors this month emphasize, the main attraction is high reliability, a quality of the first importance to the industrial user of instrumentation and control equipment.

Again, the small size of transistors is an obvious advantage. Apart from any virtues inherent in miniaturization for aircraft and guided weapon applications, their smallness leads to a reduction in chassis and box work. Unlike the thermionic valve, the transistor, of course, needs no heater supply, and its power consumption is low (by changing from valves to transistors one user has reduced the power consumption of a particular unit from 200 watts to 1·8 watts). This is especially advantageous in applications where ventilation and cooling are difficult (in a computer, for example). Furthermore, transistors are certainly more reliable than valves when subjected to rapid acceleration, an important point in g.w. work.

What of the technical disadvantages? These are to a great extent bound up with their, at present, comparatively poor temperature characteristics and their poor response at the higher frequencies. Most transistors in use are of the germanium junction type (the point contact transistor appears to have faded away) and these give of their best at temperatures little higher than room temperature. The newer silicon junction types, which are now becoming available, have much better temperature characteristics—working temperatures as high as 200°C may be practicable.

This often means that circuits for transistor equipment are harder for the newcomer to design than valve circuits because another parameter, temperature, must be taken into account. On the other hand, it is true that many transistor circuits are basically simple, and involve few components.

Turning to costs, we find that germanium types cost around 50% more than the corresponding valves, and silicon transistors may be many times as expensive. Furthermore, a dual valve costs much the same as a single valve, and as one designer recently said, 'we always seem to finish up using more transistors than we did valves'.

But transistors do certain jobs better than valves; the transistor switch is a good example of a device for which valve techniques are less suitable. First cost indeed is irrelevant to a great extent. Function for function, valves are cheaper to use than transistors, but other advantages of the transistor appear to rule out cost as a deciding factor.

Moreover the present comparatively high first cost of the transistor must come down as larger quantities are ordered. There are eight or nine manufacturers of transistors in Britain at the moment—the industry is sometimes compared with the valve industry in the mid-nineteen-twenties—and however they fare individually, the industry as a whole is bound to be successful.

What of the future? Kilomegacycle transistors are now on the way and so are higher power devices—an 80 watt 25 amp transistor will be unveiled shortly. One transistor for which a great future is foreseen is the thyratron-type controlled rectifier. Transistor motor speed controls are not very far off. These are only a few examples of many new developments in transistors and their applications which will be discussed at Earls Court.

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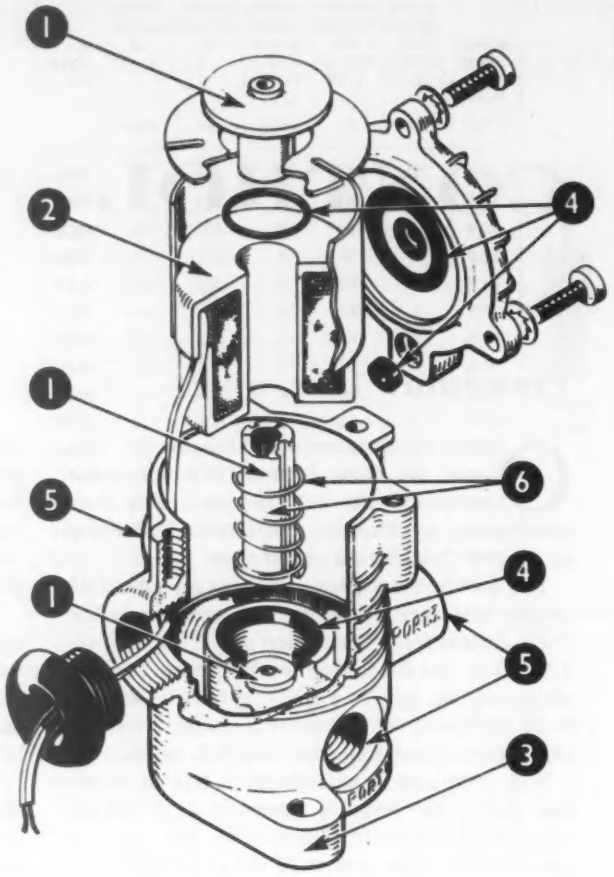

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INDUSTRY'S VIEWPOINT

A monthly article by a prominent man in the control industry on a subject chosen by himself

Dudley Saward, Managing Director of Texas Instruments, calls for cooperation between the industries making . . .

SEMICONDUCTORS AND CONTROL EQUIPMENT

THIS MONTH SEES THE OCCASION OF THE FIRST MAJOR convention in this country devoted specifically to semiconductor devices. Previous contributors to *Industry's Viewpoint* have pointed to the need for higher component reliability and standardization in control applications, increased data-reduction instrumentation in quality control and closer cooperation between the designer and the user of control equipment. The semiconductor industry is vitally concerned in all these aspects of automatic control development and the period of the IEE Transistor Convention is, therefore, appropriate for an examination of why and how.

The systems engineer is demanding more complete control of more complex processes, and his demands represent a serious problem in terms of the reliability of components.

The special quality valves developed in recent years are a considerable advance on their predecessors, but there is still a hard core of resistance to the use of thermionic devices which fail to combine ruggedness, reliability, low power consumption and smallness in size. Semiconductor devices, on the other hand, have been designed from the outset to meet these stringent requirements because they were demanded by guided missile and piloted aircraft control applications. Owing to the comparatively recent introduction of commercially available transistors, it is difficult to quote firm figures for reliability, but it is now generally accepted, in these particularly critical fields, that the use of semiconductor devices represents a considerable advance on valve equipment. Even the most consistent opponent to the use of thermionic valves in industrial control will be influenced by the obvious advantages of the metal-cased transistor and will be more ready to accept electronic control equipment in the future.

The question of standardizing transistor dimensions is receiving considerable attention. It seems probable that the standard case already widely adopted by American manufacturers will shortly be accepted in this country and also in all NATO member countries.

What of future developments in the field of semiconductor components? The most important in the next few years will undoubtedly be solid-state circuitry, with both active and passive components forming integral parts of a single piece of semiconductor material.

Developmental circuits have already been demonstrated—one a multivibrator circuit measuring $\frac{1}{4}$ in. × $\frac{1}{8}$ in. × $\frac{3}{32}$ in.—which give component densities of several million components per cubic foot! These techniques will permit fantastic reductions in the size of complex control equipment.

Cooperation between the control and semiconductor industries, in the application of instrumentation to process control and automation to device assembly, can accelerate current and future developments in both industries. We in the semiconductor industry can benefit enormously from the experience of the control engineer. The production of single-crystal material suitable for device manufacture demands temperature control to within less than $\frac{1}{2}$°C at 1420°C. The extension of automation to device assembly calls for indexing and transfer mechanisms and, for micro-manipulation, controls with accuracies much better than one-thousandth of an inch. Cooperation in these, and other spheres, will be mutually beneficial, bringing higher component reliability, increased yields and lower priced devices—important inducements to more rapid investment in instrumentation and control throughout British industry.

In partnership we can make a significant contribution to the improvement of Britain's position in world markets.

Dudley Saward

This down-to-earth article clarifies the use of transistors for the engineer or technical manager not specialized in electronics

Transistors in Industry

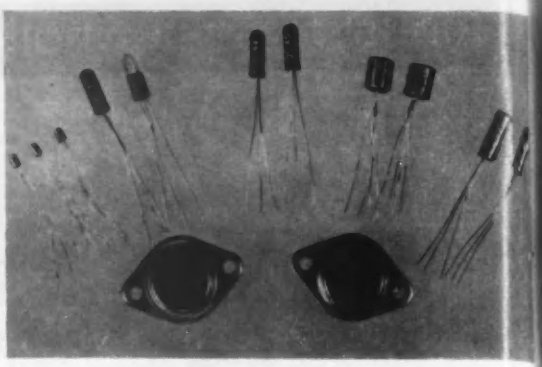


Fig. 1 Typical range of transistors

by **E. WOLFENDALE, B.SC. (ENG.), A.M.I.E.E.**
The Mullard Radio Valve Co., Ltd.

THE TRANSISTOR IS A DEVICE WHICH WILL MAKE THE Second Industrial Revolution possible. Dr H. A. Thomas has shown in his 1958/59 Faraday Lecture(*1*) that the Second Industrial Revolution will be brought about by automation, or the widespread use of electronic control gear in industry. This control gear will be either so complex or, on the other hand, so simple that it could not be designed using thermionic valves. This statement raises a number of interesting points which it is my purpose to try to answer.

The first and most obvious question is, what are the advantages of the transistor over the thermionic valve? The obvious advantages are, of course, small size, very robust construction, no heating power required to make the device ready for operation, and a very much smaller operating power from low voltage power supplies. The other questions are: what is a transistor?; how is it going to be used?; and how reliable will the equipment be in which it is used?

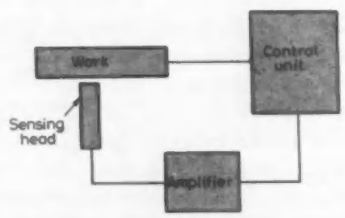


Fig. 2 A simple control system

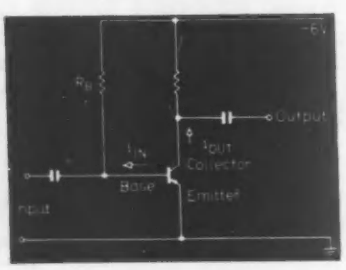


Fig. 3 The transistor as a simple amplifier

Let us take the transistor itself first. Basically it is an amplifying device which can be used to amplify small signals, or to operate as a switch to control large or small signals. A number of different types of transistor are illustrated in Fig. 1. On the left are small subminiature transistors used in hearing aids; these may be used as a guide to the size of the other transistors as their can dimensions are 4mm by 3mm. The next transistor is a general purpose type used for low frequencies, and alongside this is a phototransistor. The two in the centre are general-purpose types for high frequencies, and to the right of them are two v.h.f. transistors. On the extreme right, are two low power transistors, and underneath them all are two power transistors capable of controlling up to 100 W.

Transistor characteristics

The performance of a transistor is defined by a large number of characteristics, but the three most important are listed as follows:

1. The current gain of the transistor. This partially defines the ability of the transistor to amplify.
2. The frequency cut-off, or, as now commonly used, the frequency at which the current gain becomes unity. This indicates the frequency of the signal which can be amplified by the transistor, together with the speed at which it will operate as a switch.
3. The thermal resistance from the transistor inside its

envelope to the ambient air surrounding it, and also the temperature at which the transistor is allowed to operate—the maximum allowable junction temperature. These define the amount of power the transistor is capable of dissipating and hence the amount of power it will handle in a control circuit. The larger power transistors are constructed so that they can be screwed down onto a heat sink, to enable the power dissipated by the transistor to be conducted away to the ambient air surrounding it.

Simple control systems

How is the transistor used in simple control systems, in automation, and in instrumentation?

Let us take the simple control system first. As shown in Fig. 2 this consists of a sensing element from which the control information is derived, an amplifier, and a control unit.

How do transistors play their part in this system? First, some transistors can be used as a sensing element; where light is used to sense the work, a phototransistor can be fitted(*2*). Usually the sensing element has to be close to the work and, in general, provides a small output only. The output of the sensing element has, therefore, to be amplified to a level sufficient to operate the control unit.

Fig. 3 shows how the transistor is used to amplify. The input signal is fed into the base in the form of a base current i_{IN}. A small voltage only is needed to produce this current as the transistor has a low input resistance. The transistor is a current amplifier and has a current gain between collector and base of about 50, and so a considerably amplified current may be taken at the output from the collector. The simple method of biasing shown, using a single resistor R_B, has to be modified in practice to take into account variations due to temperature(*3*).

If the sensing element produces very small signals, it is necessary to position the amplifier close to the sensing element so that the signal from the element may be transmitted to the control unit, which may be some distance away, over a cable at high level. If the signal was transmitted at a low level, any interference pulses picked up on the cable would disturb the control signal and produce errors in the work. In this sort of system transistors have every advantage over the thermionic valve because of their small size and low power consumption. They may, in fact, be made into an amplifier which can

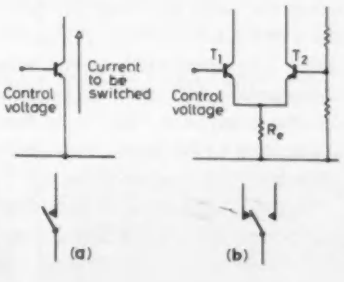


Fig. 4 The transistor as a switch: (a) on-off; (b) change-over

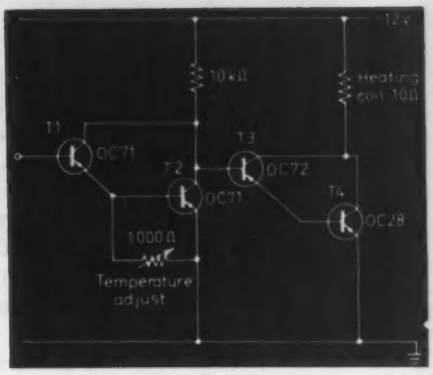


Fig. 5 The temperature control circuit. Transistors T1, T2 and T3 are mounted inside a temperature-controlled metal block

be built into the sensing head and thus transmit the signal from the sensing head at a very high level down the cable.

The transistor switch

In general, the control unit consists of a switch. Many control units have been made using mechanical relays, but these have a short life and become unreliable because of contact troubles. The transistor can be used as a switch, and hence the control unit itself may be built using transistors; this eliminates mechanical contacts and makes for much more reliable equipment.

Fig. 4 shows, in outline, the transistor as a switch. The on-off switch given in (*a*) is the amplifier previously described. In this case, the base voltage controlling the transistor is either such that no current flows between emitter and collector, or that the full operating current flows. The change-over switch in (*b*) uses two transistors and the current in the resistor R_e flows through one or the other. The base of the right-hand transistor is held at a voltage which defines the current to be switched, as it is this potential which appears across R_e. When the control voltage which is applied to the base of the left-hand transistor is such that this transistor is 'off', all the current from R_e flows through $T2$. When however the control voltage is such that $T1$ is 'on', then the current from R_e is diverted to $T1$ and $T2$ is cut off.

Sense, amplify and control

To show how the transistor can be used in a simple control system, I will give an example (*4*). This is not directly applicable to mechanical control systems but illustrates the use of the transistor in a sensing element, in an amplifier, and in a control unit. The problem was to control the temperature of a small block of copper or aluminium, and to keep its temperature essentially constant at about 45°C with normal changes in ambient temperature.

First, the sensing element. This must sense not only the temperature of the block but also very small changes in its temperature. As transistor current is temperature dependent the transistor can be used to sense the temperature of the block and small changes of temperature in the block. This current is small and must be amplified before it can be used to operate the control unit, which

in this case is a heating element around the block. The circuit is shown in Fig. 5.

Transistor $T1$ is the sensing element and its current is fed into the base of the second transistor $T2$. As a transistor has a current gain between collector and base, the current from the sensing transistor is amplified by the second transistor. The current from the third transistor $T3$ operates the power transistor $T4$, an OC28.

If the temperature of the block rises, the current in the sensing transistor $T1$ goes up and hence the current in $T2$ rises. This brings the potential at the collector of the transistor $T2$ down, reduces the current in $T3$ and in the power transistor $T4$, thus reducing the heating in the coil in the collector of power transistor $T4$, and hence the heating around the block. If the temperature goes down the reverse process takes place. In a practical amplifier the variation in ambient temperature can be reduced by a factor of about 50.

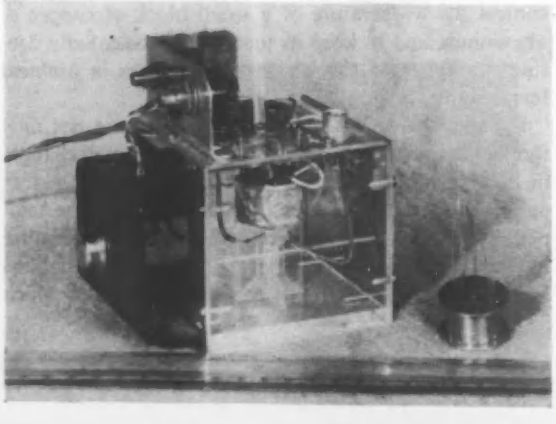
A demonstration model of this unit is shown in Fig. 6, where it is being used to control the temperature of a very sensitive transistor d.c. amplifier. The small block, a duplicate of which is shown on the right, is wrapped in metal foil and mounted inside a Perspex box to prevent sudden changes in ambient temperature due to draughts. On the left is the power transistor used to supply the current to heat the block. It is mounted on a blackened heat sink. On top of the box are two preset controls for setting up the temperature of the block and the balance of the amplifier.

This is, of course, only a simplified illustration of how transistors can be used. In practice, the sensing element could be a thermocouple, strain gauge, flow meter, thickness gauge etc., and the output from these would be amplified according to the type of signal produced, whether a.c. or d.c. The control unit could consist of a motor driving a lathe, adjusting a valve, controlling the speed of a belt, etc.

Computer control

Let us now turn to the more complicated automation systems. These are, in essence, a number of simple control systems, the outputs of which can be controlled directly and whose settings are dependent upon each other. In true automation, a central computer decides on the relative settings of all the controls upon the information derived from a number of sensing elements, as shown in Fig. 7.

Fig. 6 The complete temperature control system of Fig. 5 in operation



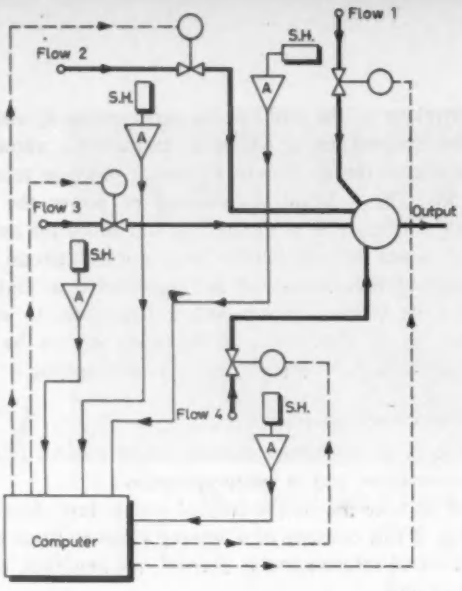


Fig. 7 A complex control system using a computer

The computer takes the information from the sensing elements and, according to a prearranged programme, sets the various control units to the desired levels. A computer will do this in an extremely short time, even though the calculation required to decide the relative settings of the control units is extremely complex. The computer could be replaced by a human operator with a slide rule, but the time he would take to calculate the various settings of the control units would be so long that at the end of it the outputs from the sensing elements would have changed and his calculated settings would be of no value. The computer can do this so quickly that to an observer it appears that the control units are being continually changed, although in fact the computer is stopping and looking and then changing.

The computer can handle the problem only by breaking it down into simple terms. It can use simple binary addition and subtraction only, and so all problems presented to it have to be changed into binary code. The code is then fed into the computer, stored, and the computer will then operate on it. As the problems have to be broken down into such simple terms, they become highly repetitive in the computer and a large number of active devices are required to perform the operations. When these active devices are thermionic valves the computer is extremely large, has very heavy power consumption, with the resultant problem of getting quantities of heat away from within the cabinets of the computer. The transistor however, with its very small power consumption and small size, can be used to make small reliable computers, and it is these which will enable automation to become a practical proposition in many of our present-day industries.

A computer may use many thousands of transistors and diodes, but nevertheless transistors reduce the size and complexity of this type of equipment. Figs. 8 and

9 show a portable electronic counter made with about eighty transistors; yet is operated off the small dry battery lying at the back of the instrument.

The transistor in instrumentation

The third use is in instrumentation. Here again the transistor is used as an amplifier. In instrumentation the output from some form of sensing element must be indicated either on a meter or on a pen recorder. Meters and pen recorders which will operate from very small currents can be made, but they are expensive and very fragile. Robust and heavy instruments require large current for their operation, and so it is necessary to amplify the outputs from the sensing elements. Here again the transistor provides a great advantage as it can, if necessary, be built into the instrument case itself.

An amplifier (*5*) which can be used to take the output from a thermocouple and record the temperature on a robust meter is shown in Fig.10. The input is applied between the bases of the first two transistors and the amplifier is made up of pairs of transistors. This reduces considerably any drift in the amplifier output due to variations in ambient temperature. The overall drift referred to the input is approximately 0·1 mV/°C.

Transistors will also make possible a new range of instruments using more sensitive sensing elements. For example, using what is known as the Hall Effect in a semiconductor, it will be possible to measure direct currents of a few milliamperes without interrupting the circuit, by measuring the magnetic field produced around the conductor by these small currents. A transistor amplifier will be used to amplify the signal to a level sufficient to operate a robust meter.

Extreme reliability

Finally we come to the question of reliability. Here the transistor has every advantage, not only because it is reliable in itself but because it increases the reliability of the components associated with it, as they are all run well below their voltage rating and at reasonable temperatures.

What do we mean by the life of a transistor? The life of a thermionic valve is easy to define because the end point is fairly abrupt, but the characteristics of a transistor show only a very gradual deterioration during life. This means that the life of the transistor in its circuit is determined by the circuit designer. If he designs the circuit to accept a wide range of transistor parameters and allows for deterioration of these parameters during life, then the life in the circuit will be extremely long, in fact

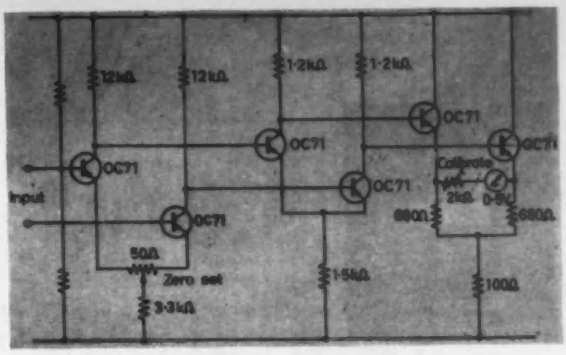


Fig. 10 This long-tailed-pair transistor amplifier may accept thermocouple currents and amplify them to a level sufficient to operate a robust meter

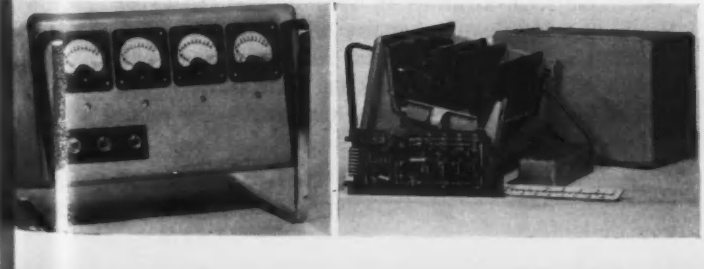
we may almost say the life in the circuit will be indefinite. All indications at the moment would seem to show the latter estimates to be reliable. However, we have not had sufficient time to confirm these indications. Transistors have not been in mass production long enough for us to say at the moment whether they will last ten or twenty years, and what the characteristics are going to be like after these time intervals. There are, however, indications that the silicon alloy transistor may be very much more stable when operated at normal temperatures than the germanium transistor, but again they have not been in mass production long enough for us to be able to indicate what they are going to be like in ten or twenty years' time.

Finally the question of maintenance. If transistors are as reliable as we think and their effect on their associated components is as we expect, then maintenance should not be required. A properly designed and reliable instrument will go on indefinitely with only small changes in its transistors or components.

One would expect, therefore, that in the future the easiest method of maintenance would be for the transistors and their associated circuits to be wired in the form of replaceable units. If additional reliability is required, two, or perhaps even three, such units could be operated in parallel so that if one failed the others would continue to provide the necessary output. Transistor circuits could then be built in to indicate when such a unit had failed, so that it could be replaced.

This, however, is looking into the future. At present, while we are gaining experience in the manufacture of transistors and the design of transistor circuits, some maintenance will obviously be necessary, but this should be considerably less than that required with thermionic valve equipments. Present experience in the only market in which transistors have been widely used over a number of years, the hearing aid market, indicates that the number of failures of transistors will be extremely small.

Figs. 8 and 9 A portable transistor counter which incorporates 80 transistors, yet operates off a small dry battery



Acknowledgments

The author wishes to thank all the manufacturers who very kindly sent him information on their control equipment using transistors, and also the directors of the Mullard Radio Valve Company Ltd for permission to publish the article.

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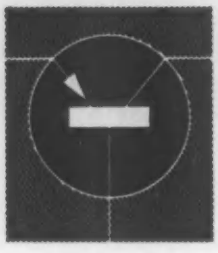


D.C. is better than a.c. for most transistorized control systems

Transistors— their effect on instrument design

by **P. COWLIN, B.SC., A.INST.P.**
Bailey Meters and Controls Ltd.

CONTROL INSTRUMENTATION IS A WIDE FIELD, COVERING at one extreme the simple on-off controller added to an indicating instrument, and at the other complex and comprehensive plant control schemes calling for perhaps three or four control loops each with its measuring element and transmitter, its two- or three-term controlling unit, and its regulating element. Throughout the control field the characteristic features of transistors can be exploited to advantage, while knowledgeable circuit design enables the difficulties to be surmounted. Many of these characteristics are now common knowledge, and are summarized in other articles in this issue.

Indicator-controllers

The simple on-off relay circuit controlled by the movement of the pointer of a galvanometer instrument, or other mechanical displacement, presents little design difficulty and applies two great advantages of transistor circuits. Apart from the greater reliability inherent in the solid-state device, such circuits avoid the disturbance of the pointer which, with a valve circuit, can be caused by the convection currents due to the heater dissipation unless very great care is taken over the mechanical layout; this is true even of the photoelectric transistor circuit since the lamp dissipation can be kept quite small, and the other widely used type incorporating an inductively coupled oscillator is completely free of the trouble. In both types the small size of the transistor or phototransistor facilitates the design of compact units well suited for mounting inside the galvanometer housing. These indicator alarms are frequently operated from thermocouples, and the slow approach to the alarm point means that all possible ratios of division of power between transistor and load are gone through sufficiently slowly to damage the transistor, if, in any of these states, the maximum permissible dissipation is exceeded; this sets a rather severe limit to the operating power of the relay that can be used. The provision of a trigger circuit in which an additional transistor is coupled to the phototransistor ensures a practically instantaneous transition of the second, load-carrying transistor between two states of low dissipation, however slowly the alarm point is approached, and practically removes this limitation.

Units for control schemes

Turning now to more complex types of control instruments, these have, in general, the task of amplifying small signals, nearly always either d.c. or relatively low frequency a.c., with power outputs sufficient for robust indicators, relays, motors or some sort of power-amplifying device such as an electrohydraulic positioner. The standard of accuracy required is usually somewhat less than that expected in a good laboratory instrument, but the maintenance of this standard, together with great reliability and the ability to operate for very long periods without attention in an industrial environment, is of the utmost importance. Fail-safe design in respect of the failure of the most vulnerable components and in particular of electrical supply failure is being paid increasing attention, and in some plants intrinsic safety and flameproof design are important.

Transistorized equipment is by its nature easier to design to meet these requirements than thermionic units. The transistor is more compatible with the use of printed circuits and the low voltages existing between adjacent elements of such circuits render the units to a large extent immune to insulation problems arising in dusty atmospheres; alternatively, the absence of heater power makes the hermetic sealing of whole units entirely practical. The relatively few indus-

trial applications where high ambient temperature prohibits the use of germanium transistors can now be tackled with silicon transistors, though these are, and will be for some time, considerably more costly.

A.C. amplifiers

Some general difficulties may be illustrated from the design of a simple low-frequency a.c. amplifier, intended to be fed with the out-of-balance voltage from a Wheatstone bridge or a differential transformer, and to operate an alarm relay at a specified signal level. Such a circuit can never be operated as a strict null-detector since a finite input is required to hold the relay in, but this ideal can be approached sufficiently to reap the advantage of comparative unimportance of amplifier gain variation. The bridge or transformer excitation is usually at 50 c/s for convenience, and this combined with the typically low input impedance of a transistor stage, even in the common-emitter configuration, produces the first difficulty: that of achieving sufficiently long time-constants in interstage coupling and emitter decoupling. It is only comparatively recently, and entirely owing to the requirements of transistor circuits, that components such as electrolytic capacitors of sufficiently high value, working voltage and reliability, and small inter-stage transformers with high primary inductance, have become available.

Temperature variations are important not so much for their direct effect on the gain, which is slight, but for their effect on the working point of a transistor and the consequent gain change. It is essential to use one of the well-known methods of working-point stabilization *(1)* (d.c. feedback from collector to base on each stage, or d.c. emitter degeneration together with a low-resistance voltage-divider to provide base bias), particularly in later stages where the signal amplitude is comparable with the collector supply voltage so that any appreciable change in working point may produce gross distortion. With such precautions, the gain stability is quite adequate for this type of application. A phase-conscious rectifier is needed to supply the relay, and where the magnitude of quadrature-phase interference is small the simplest possible circuit—a single transistor operating with half-wave-rectified collector supply and using the base-to-emitter diode for synchronous rectification of the signal—is satisfactory. (Fig. 1 shows the essential features of a circuit designed on these lines.)

Use of negative feedback

In many applications the null-detector principle cannot be applied and some use of negative feedback will be necessary for gain stabilization. Each stage can have a partially undecoupled emitter resistance to provide degeneration, but this is often insufficient and the more powerful method of feedback over two or more stages is used. More care is necessary than with a corresponding number of valve stages, because a transistor has an inherent phase lag which, particularly in the common-emitter configuration, increases rapidly with increasing frequency. With three or more cascaded stages this results in severe limitation on the amount of feedback that can be applied before oscillation at high frequency is caused by the cumulative phase shift. The use of r.f. types of transistor, with smaller inherent lags assists in this respect but with some increase in cost, while phase-correcting networks in the feedback loop can be used to extend the feedback range *(2)*.

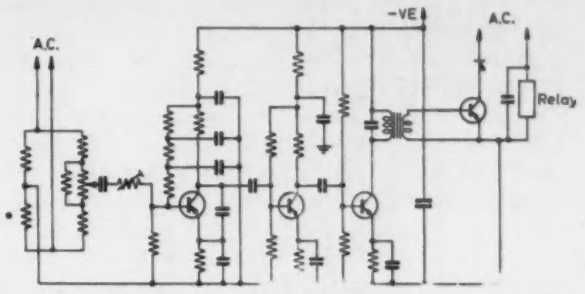
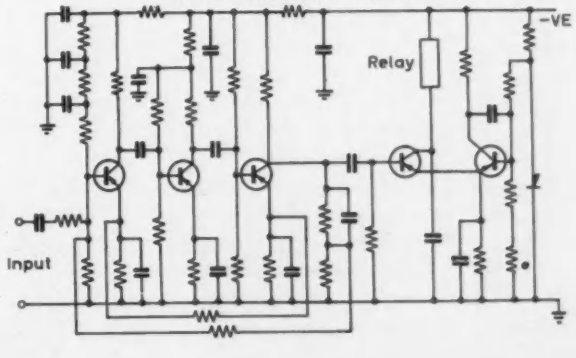


Fig 1. The simple a.c. null detector uses four transistors

A further difficulty experienced in applying negative feedback is that the input impedance of a transistor can vary with temperature, supply voltage and time, and unless this is allowed for in the design, the feedback fraction actually obtained varies correspondingly. It is usually possible to apply the feedback to a stage with its internal input impedance increased by its own feedback loop, such as an emitter follower *(3)*, so that the feedback fraction is determined by a passive external resistor; another possibility is to use feedback current, rather than voltage, derived from a current source, so that the impedance into which it is fed is unimportant.

An example of this type of unit is an acoustic flame failure detector whose input is derived from a microphone which receives the noise generated by a furnace flame. This particular unit was originally required to have a wide frequency response, and the feedback methods adopted (see Fig. 2) result in a response flat within ½% between 100 and 4000 c/s, as illustrated in Fig. 3. The converse of this is often required, and although limited selectivity is easy enough to achieve—the introduction of one tuned-transformer stage is often sufficient—a sharply selective response is quite difficult. This is because of the low input and output impedances

Fig. 2 A transistorized gain a.c. amplifier, with feedback stabilization and a d.c. comparator. The unit is used in an acoustic flame failure detector



of transistor stages, which act as damping resistances in parallel with tuned circuits, and in general it is impossible to realize anything approaching the Q of the passive circuit except where considerable attenuation is permissible, so that the tuned circuit can be isolated on each side by large resistors. Alternatively one can often use emitter followers to present a high impedance to the tuned circuit without attenuation. Where a really sharply tuned response is required positive feedback can be applied (*4*) to obtain a Q higher than that of the passive circuit.

D.C. amplifiers

The handling of d.c. signals at once presents much more difficult problems; the various effects of temperature, supply voltage and ageing, instead of merely altering working points with only indirect effect on gain and signal level, now produce disturbances which are indistinguishable from signal changes. The temperature stabilization techniques mentioned above for a.c. circuits are quite useless in direct-coupled amplifiers and indeed any technique relying entirely on negative feedback is ruled out.

The most generally applied technique for direct-coupled amplifiers is that of pairing transistors in such a way that the temperature drifts and supply voltage drifts of the two transistors are opposed; a favourite method is the use of cascaded long-tailed pairs as differential amplifiers, and many such circuits have been published. In my experience such circuits, although acceptable for laboratory use, are extremely difficult to use in industrial applications; the chief difficulty is that while at any given moment almost perfect balancing can be achieved by correct setting of the appropriate associated resistors, this is valid over only a limited range of temperature and voltage, and will in any case require resetting after only a comparatively short time. A further difficulty in industrial control applications, where a series of interconnecting instruments if often called for, is that for convenience in such connexions each individual instrument should have input and output either completely isolated or with a common (usually earthed) terminal; the balanced direct-coupled amplifier satisfies neither requirement but instead connects input and output terminals by an indeterminate resistance. Where no interconnexion is required this difficulty of course disappears, and one balanced stage can often be used at the output of an instrument. The acoustic flame failure unit already quoted shows an example of this: the output stage consists of a transistor the base-emitter diode of which acts as a biased rectifier, the bias voltage being fed by the common-emitter connexion from a second transistor. The temperature effects can be analysed as due to two parameters: change in base-emitter voltage for constant collector current, which is almost completely compensated by the similar change in the second transistor, and change in collector leakage current, which is minimized by choosing a type having a very low value of this parameter. One might try to attain further balance by connecting the load between the two collectors, but the reduced power gain resulting would have necessitated a further stage of amplification, with the difficulties of achieving good balance more than doubled.

Use of silicon transistors

Where much greater amplification at zero frequency is required—for example when the input to the entire amplifier is the low direct voltage from a thermocouple —the practical difficulties of using direct-coupled stages are prohibitive even if the large extra cost of silicon transistors can be tolerated. (It should be noted that although silicon transistors have much lower collector leakage currents the base-emitter voltage effect is of the same order as in germanium transistors, and still necessitates balanced pairs, while in general somewhat more silicon pairs are needed to obtain the same gain.) The choice therefore lies between modulator-type amplifiers and direct-coupled amplifiers with a subsidiary drift-correcting amplifier of the modulator type; and except in the very rare cases where a frequency response extending from zero to very high frequency justifies the cost of the latter type, economic considerations will dictate the simple modulator type.

The transistor modulator

In the modulator type of amplifier the drift problems of the amplifier proper are negligible since it is an a.c. amplifier which can use the stabilization techniques discussed above, and it is only necessary to consider the drift of the modulator, demodulator and output stage. Of the three available types— electromechanical, diode and transistor—the electromechanical, while capable of giving excellent results if properly adjusted, is frequently a source of trouble when reliable long-term performance is expected, and is quite costly; it is also somewhat severely limited in possible modulation frequency. The diode modulator has a poor switching efficiency for low-level signals, and is also dependent, for freedom from drift, on the use of expensive silicon diodes, which must usually be driven with a rather large square-waveform current. The transistor modulator, using one or two transistors, also requires a square-wave drive but of appreciably less power; it yields high switching efficiency over a large range of modulation frequencies and its temperature drift can be kept very small, even in the single-transistor version (*5*), where it is possible to oppose the changes of two parameters in the same transistor. Its chief disadvantage is the somewhat low upper limit on the source impedance with which the temperature performance can be maintained, but this limitation is unimportant for such sources as thermocouples, or a low resistance fed from a remote current transmitter.

The combination of such a modulator with a highly stabilized reference voltage, an a.c. amplifier and a phase-conscious rectifier, yields a d.c. equivalent of the a.c. quasi-null-detector already described, suitable for

over-temperature alarm or for on-off control of furnaces, and a very high stability of the set point can be achieved. The gain-stabilization of the a.c. amplifier will not change such a device into a d.c. amplifier of overall high gain stability, since the modulator and rectifier are outside the feedback loop. It is, however, possible to apply d.c. feedback from output to input so as to stabilize the whole circuit very satisfactorily, and a unit with quite high input impedance and with either output current or output voltage stabilized is achieved, according to the type of feedback used.

Control systems

So far only individual units, of varying degrees of complexity, have been considered, but what chiefly interests the process control systems engineer is the combination of such instruments into a unified system, and the characteristics of such a system.

A d.c. amplifier with overall stabilization can be utilized as a very satisfactory transmitter, amplifying the voltage from a thermocouple or a d.c. bridge and transmitting a signal to a remote control unit; a similar arrangement of the basic a.c. amplifier can deal with signals from a.c. bridges or differential transformers, and thus with displacements and forces. In either the feedback could be arranged to give alternating or direct current or voltage as the transmitted signal, and it is of interest to ignore temporarily the more general arguments for or against these systems and to consider only the question of suitability for transistorized equipment. One might expect, in view of the above remarks concerning the difficulties of d.c. amplification, that an a.c. system would be easier, but this is not the case; whichever system is chosen, inputs of both kinds must be dealt with, and it is easier to arrange the output signal from a stabilized a.c. amplifier to be d.c. than vice versa. Again, although a purely proportional controller would probably be no more difficult working with a.c. than with d.c., as soon as integral or derivative forms are required it is practically inevitable to handle the signal as d.c. at some stage in the controller, and this immediately weighs the balance in favour of a d.c. transmission system.

The transmitted signal must be compared with a desired value at the controller input and the stability of the desired value is of great importance; it is obviously much simpler to derive a d.c. desired value from a reference source such as a Zener diode than to derive an a.c. desired value, the phase of which must be identical with that of the remote signal.

Voltage and current transmission

The arguments for voltage or current systems in terms of special compatibility with transistor circuits are not quite so conclusive, but on the whole favour a current system. In order to use voltage transmission it is necessary to have at the receiver an input impedance some two orders higher than the highest line resistance required by the system; if feedback is used

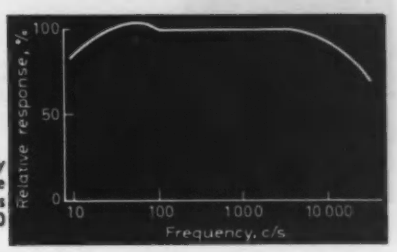


Fig. 3 The frequency response of the amplifier in Fig. 2 is flat between 100 and 4000 c/s

to achieve this, as is inevitable, the actual magnitude will depend on an open loop gain and will therefore need to be still higher to render its fluctuations unimportant. In a current system, the most usual version of which is to feed a transmitted current into a stable, passive resistance and to amplify the voltage developed across this, the need for magnitude and stability of the amplifier input impedance is appreciably less stringent. Again, the consistent use of current sources often requires a 'floating' collector voltage supply; this is not at all difficult with the magnitudes of voltages called for by transistor circuits, whereas in corresponding valve circuits the existence of a number of floating high-voltage supplies is a little unsatisfactory.

Thus the strong and well-known general arguments in favour of a direct current transmission system can be supported by the contention that such a system is in fact most compatible with transistorized equipment.

Conclusion

Summarizing this brief survey, one can say that the application of transistor circuit techniques to control equipment is expected to produce compact units which can be readily sealed without incurring large temperature rises. The absence of temperature gradients within a unit greatly facilitates such matters as cold junction compensation, while the size and cost of a flameproof housing will clearly be considerably less than that required for a comparable thermionic unit. All the unit devices mentioned can if necessary operate from a low-voltage a.c. supply rather than conventional mains, and also, with some additional cost in some cases, from battery supplies; these points are very important for applications demanding intrinsic safety. Units can be made which will meet all the requirements of typical control loops, and while able to fit in with any transmission system they are most suitable for a direct current system. The cost of such units, in the present state of transistor technique, may be expected to be somewhat higher than that of thermionic units which might give comparable characteristics when tested 'on the bench', but the rapidly advancing art gives good reason to expect that this will soon cease to be true.

Acknowledgment

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3. *Electronics*, May 1955, p. 174
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5. Brit. Pat. App. No. 22990/57

TRANSISTORS

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A BRIEF SURVEY IS MADE OF SEMI-conductor materials and transistors and some of their more important properties are discussed. The use of the data sheets to enable the engineer to select suitable transistors and design transistor circuits is also indicated.

Semiconductor materials

The elements in Group 4 of the periodic system of the elements have four electrons called valence electrons, which can take part in chemical bonding. The strength of the bond depends upon the particular element, and the energy required to break the bond is expressed in electron-volts. For a temperature at, or near, zero on the absolute temperature scale the crystal does not possess enough thermal energy to cause any of these bonds to break. No electron can thus take part in electrical conduction and the material behaves like a perfect insulator. As the temperature is increased the thermal energy acquired by the crystal causes some of the covalent bonds to be broken and electrons then are able to take part in electrical conduction. Thus crystal conductivity increases as the temperature increases. Materials which behave in this fashion are called semiconductors and are not necessarily confined to elements found in Group 4.

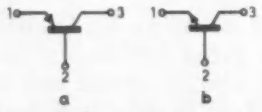


Fig. 1 **a.** Symbol for a *p-n-p* transistor; **b.** Symbol for a *n-p-n* transistor. Electrode 1 being the emitter, 2 the base and 3 the collector

The symbol may be encircled, as shown at the top of the page.

Table I shows some of the more important semiconductor materials from a transistor point of view, their maximum operating temperatures and maximum theoretical operating frequencies. It will be noted that germanium compares very favourably with silicon when the temperature of the junction is at, or near, room temperature. For low power applications at high frequencies germanium is to be preferred to silicon but at high powers, where the energy dissipated raises the temperature of the transistor itself, silicon is preferred to germanium.

From Table I(*1*) it can be seen that gallium arsenide, having a superior maximum frequency of operation than germanium and yet a higher operating temperature than silicon, would seem to be a most promising material. Great interest is centred on this material at the moment and it may well prove to be the standard semiconductor material of the future.

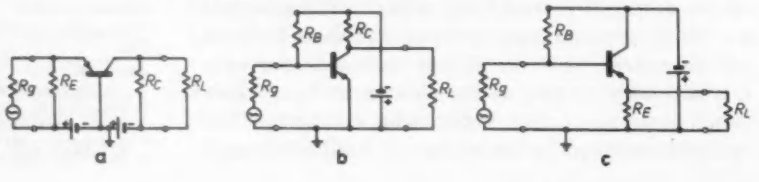
The transistor

Impurities from other groups can be present or introduced into the crystal lattice, which means that either too many or too few electrons are available to satisfy the covalent structure. If too many electrons are available the material is called *n*-type, if too few *p*-type. If electrons are made to flow into *n*-type material these electrons are majority carriers. If, however, electrons are introduced into *p*-type material they are minority carriers. In structures such as the *p-n-p* or *n-p-n* transistor, minority carriers are injected into the base of the transistor from the emitter (where, of course, they are majority carriers). Such devices are called *bipolar* transistors. In order to transfer carriers from emitter to collector the process of injection of minority carriers into the base from the emitter is a low impedance process. The input impedance of a bipolar transistor is thus inherently low which, for most purposes, is a considerable disadvantage. Similarly, the output impedance is inherently high from base to collector.

Devices which operate entirely with majority carriers such as the analogue(*2*) and field effect transistor(*3*) are called unipolar transistors. These have a high input impedance and can have a high output impedance, thus resembling the thermionic valve in this respect. All the transistors listed in the summary are bipolar devices and very few of the unipolar type are available—yet does the future of transistors lie with the latter rather than the former? The difficulties associated with the fabrication of unipolar transistors are being overcome(*4*) and, in common with the newer semiconductor materials, they might well firmly oust thermionic valves from all but the high power at high-frequency domain.

As the behaviour of a valve and transistor can be similar, it is often difficult to decide when to use one, rather than the other. Table 2 indicates

Fig. 2 (a) The grounded base; (b) the grounded emitter; and (c) the grounded collector configurations. R_g represents the source resistance and R_L the load resistance to which the input and output are connected respectively



the regimes in which one might be preferred to the other.

Some approximate design criteria

Fig. 1 shows the usual symbol for the transistor and Fig. 2 shows three possible configurations in which it can be operated.

Table 3 shows how the input impedance R_{in} of the device can be approximately calculated by using the information found in the survey. The actual input impedance, of course, depends on the input impedance as calculated from the formulae in Table 3 in parallel with R_E in case (a) and R_B in cases (b) and (c). Thus R_E and R_B should always be very much greater than R_{in} if as high an input impedance as possible is desired.

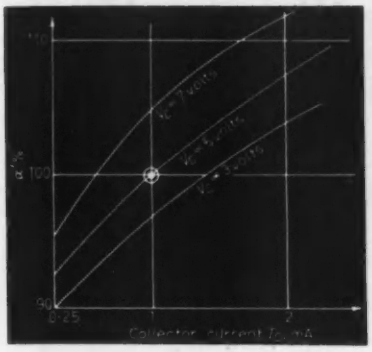


Fig. 3 The percentage variation of α' with collector current and collector voltage, $\alpha' = 100\%$ representing the value of α' quoted by the manufacturer

The approximate output impedance of the device R_{out} can be calculated by using the information given in the survey and the formulae in Table 3. The actual output impedance of the device is R_{out} in parallel with R_c.

The approximate voltage gain can be calculated by using Table 3 and remembering that this represents the gain of the device connected to an infinitely large load resistor R^L.

Fig. 4 The percentage variation of f_α with collector current and collector voltage, $f_\alpha = 100\%$ representing the value of f_α quoted by the manufacturer

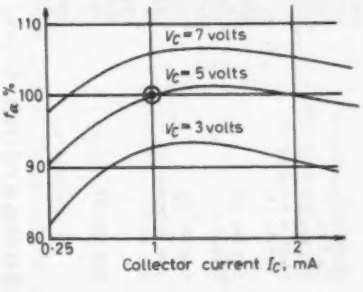


TABLE 1

ELEMENT	SYMBOL	MAX. FREQUENCY AT ROOM TEMPERATURE, Mc/s	MAXIMUM TEMPERATURE, °C	BOND STRENGTH, eV
Gallium arsenide	GaAs	1000	450	1·35
Germanium	Ge	1000	100	0·70
Indium phosphide	InP	400	400	1·25
Silicon	Si	150	250	1·10
Gallium phosphide	GaP	30	1000	2·25
Silicon carbide	SiC	30	> 1000	2·80

TABLE 2

CRITERION	VALVE	TRANSISTOR
Size		√
Weight		√
Cost	√	
Ability to withstand high accelerations		√
Ease of circuit construction		√
Demands on power supplies		√
Use in low power a.c. coupled amplifiers and switching circuits up to a few megacycles		√
Use in low power a.c. coupled amplifiers and switching circuits greater than a few megacycles	√	
Use in high power, high frequency circuits	√	
Use in multi-stage d.c. coupled amplifiers	√	
Use in circuits demanding very high input impedance	√	

TABLE 3

CONFIGURATION	INPUT IMPEDANCE, OHMS	OUTPUT IMPEDANCE, OHMS	VOLTAGE GAIN
Grounded base	A	$\frac{A+R_g}{1+10^{-4}R_g}K$	$\frac{R_c}{A}$
Grounded emitter	$\frac{4}{5}A\alpha'$	$\frac{A+\frac{R_g}{\alpha'}}{1+10^{-4}R_g}K$	$-\frac{R_c}{A}$
Grounded collector	$R_E\alpha'$	$A+\frac{R_g}{\alpha'}$	1

R_E and R_g are measured in ohms

Use of Table 3 and the information contained in the survey should enable the engineer to select the right transistor for the right job and calculate some of the more important properties of the circuits so produced.

References

1. Jenny, D. A.: *Proc. Inst. Radio Engrs.*, June 1958, p. 959.
2. Schockley, W.: *Proc. Inst. Radio Engrs.*, November 1952, p. 1289.
3. Schockley, W.: *Proc. Inst. Radio Engrs.*, November 1952, p. 1365.
4. Nelson, H.: *Proc. Inst. Radio Engrs.*, June 1958, p. 1062.

Table of transistors overleaf

Explanatory notes on the survey

α' is the ratio of the change in collector current produced by change in base current when the operating point is at some particular value of collector voltage V_c and collector current I_c. The values of α' shown in column 3 were measured at values of V_c and I_c given in columns 5 and 6.

Likewise f_α is the frequency for which, in the grounded base configuration the current gain from emitter to collector has fallen to half its d.c. value. In the grounded emitter configuration $f_{\alpha'} \simeq f_\alpha/\alpha'$, f_α being the frequency for which the α' has fallen to half its d.c. value. The value of f_α shown in column 4 was also measured at an operating point determined by V_c and I_c given in columns 5 and 6.

The manufacturer specifies the operating point at which α' and f_α are measured because they are dependent on this factor as seen from typical curves relating α' against I_c and V_c and f_α against I_c and V_c shown in Figs. 3 and 4. As one might suppose the manufacturer usually chooses his operating points in order to give favourable values of f_α and α'.

$(P_c)_{max}$, the maximum collector power dissipation is given for an ambient temperature of 25°C. This should be suitably derated for increase in ambient temperature as is indicated for the power transistor. However, it is also a factor which should be borne in mind for low power transistors, the collector power dissipation not being allowed to exceed $(P_c)_{max}/3$ when the ambient temperature rises to 50°C for germanium and 100°C for silicon transistors.

It will be noted that the recommended British Standard lead arrangement is emitter, base, collector in a clockwise fashion, the collector being marked with a white spot. Many of the manufacturers already conform to this code and it is to be hoped all will do so eventually.

Germanium *p-n-p*, low power, low frequency transistors

Manufacturer	Type number	α′	f_α, Mc/s	V_c, volts	I_c, mA	P_c max at 25°C ambient, mW	V_{cb} max, volts	A	Approximate cost	Remarks
Siemens Edison Swan Ltd.	XB 102	20— 44	<1 Mc/s	−5	1	90	−35	35	5/- to 9/-	Electrical equivalent of XB112
	XB 103	45—100	<1 Mc/s	−5	1	90	−35	30		Electrical equivalent of XB113
Tick No 220	XB 104	18— 47	<1 Mc/s	−5	1	90	−35	30		Electrical equivalent of XB114
	XC 101	67 (average)	<1 Mc/s	−5	1	150	−35	30		Electrical equivalent of XC111
Newmarket Transistors Ltd.	V 10/15A	15— 30	0·3—1·0	−4·5	1	125	−10	30	6/- to 30/-	Transistors with higher V_{cb} max available
	V 10/30A	30— 50	0·4—1·2	−4·5	1	125	−10	25		
Tick No 221	V 10/50B	50—125	0·5—2·0	−4·5	1	125	−10	20		
General Electric Co Ltd.	GET 103	35— 95	0·7—1·2	−6	1	200	−30	55	Price given on request	GET 106 low noise transistor, suitable for input stages
	GET 104	35— 95	0·7—1·2	−6	1	200	−30	55		
Tick No 222	GET 106	35— 95	0·7—1·2	−6	1	200	−15	55		
	GET 114	35— 95	0·7—1·2	−6	1	200	−15	55		
British Thomson-Houston Co. Ltd.	GT 31	20 (average)	0·8 (average)	−4·5	1	125	−9	55	Up to 10/3	Hermetically sealed version of GT1
	GT 32	40 (average)	0·9 (average)	−4·5	1	125	−9	45	Up to 11/3	Hermetically sealed version of GT2
Tick No 223	GT 33	60 (average)	1·0 (average)	−4·5	1	125	−9	40	Up to 13/6	Hermetically sealed version of GT3
Standard Telephones & Cables Ltd.	TS 13	40— 90	0·45—0·6	−9	1	75	−30	40	Price given on request	TK 21B and TK 24B symmetrical structure, suitable for switching circuits
	TS 14	20— 45	0·35—0·5	−9	1	75	−30	40		
	TS 17	40—200	0·6 (average)	−0·7	10	125	−36	40		
	TK 21B	25 (average)	2·0 (average)	−9	1	150	−30	40		
Tick No 224	TK 24B	35 (average)	2·5 (average)	−9	1	150	−30	35		
	TK 23A	35— 70	1·0 (average)	−12	1	180	−50	30		
	TK 40A	60—200	1·5 (average)	−9	1	180	−40	30		
Mullard Ltd.	OC 65	20— 40	<1 Mc/s	−2	0·5	60	−5	70	Price given on request	
	OC 66	30— 80	<1 Mc/s	−2	1	60	−5	35		
	OC 70	20— 40	0·2—1·0	−2	0·5	125	−20	70		
	OC 71	41 (average)	0·3—1·0	−2	3	125	−20	35		
	OC 72	45—120	0·35 (minimum)	−5·4	10	125	−16	—		
Tick No 225	OC 73	30— 65	0·5 (average)	−10	0·5	80	−30	—		
	OC 75	60—130	0·9 (average)	−2	3	125	−20	15		
	OC 76	45 (minimum)	0·35 (average)	−6	10	125	−32	15		
	OC 77	45 (minimum)	0·35 (average)	−6	10	125	−60	15		

Germanium *p-n-p*, low power, intermediate and high frequency transistors

Manufacturer	Type number	α′	f_α, Mc/s	V_c, volts	I_c, mA	P_c max at 25°C ambient, mW	V_{cb} max, volts	A	Approximate cost	Remarks
Siemens Edison Swan Ltd.	XS 101	20 (average)	2·5 (minimum)	−5	1	150	−12	30	12/-	XS101 symmetrical structure, suitable for switching circuits
	XA 101	20 (minimum)	5 (average)	−5	1	90	−20	25		
Tick No 226	XA 102	25 (minimum)	8 (average)	−5	1	90	−20	25		
Newmarket Transistors Ltd.	V6/R2	10— 50	2—4	−4·5	1	75	−6	15	7/3 to 42/-	Transistors with higher V_{cb} max. available
	V6/R4	30—100	4—8	−4·5	1	75	−6	25		
Tick No 227	V6/R8	50—200	8 (minimum)	−4·5	1	75	−6	20		
General Electric Co. Ltd.	GET 871	30 (average)	5 (average)	−1	25	60	−15	25	Price given on request	GET 871 suitable for switching circuits, giving rise time of 0·3μ sec.
	GET 872	60 (average)	7·5 (average)	−1	25	60	−12	25		GET 872 suitable for switching circuits, giving rise time of 0·2μ sec.
Tick No 228	GET 873	35 (average)	5 (average)	−6	1	60	−12	25		
	GET 874	40 (average)	10 (average)	−6	1	60	−12	25		
British Thomson-Houston Co. Ltd.	GT 41	15— 60	4 (average)	−4·5	1	100	−9	30	Up to 14/-	Hermetically sealed version of GT 11
	GT 42	30—100	6 (average)	−4·5	1	100	−9	25	Up to 14/6	Hermetically sealed version of GT 12
Tick No 229	GT 43	60—150	9 (average)	−4·5	1	100	−9	25	Up to 15/6	Hermetically sealed version of GT 13
Standard Telephones & Cables Ltd.	TS 7	28 (average)	4 (average)	−4·5	1	75	−20	25	Price given on request	Symmetrical structures, suitable for switching circuits
	TS 8	60 (average)	8·5 (average)	−4·5	1	75	−10	25		
	TK 20B	20—100	3—8	−4·5	1	150	−30	25		
Tick No 230	TK 25B	20—150	10 (average)	−4·5	1	150	−20	25		
Mullard Ltd.	OC 44	40—225	7·5—30	−6	1	70	−10	25	Price given on request	
	OC 45	25—125	3 —12	−6	1	70	−10	25		
Tick No 231	OC 170	80 (average)	70 (average)	−6	1	100	−20	25		
Semiconductors Ltd.	SB 344	11— 33	30—50*	−3	0·5	40	−5	100	21/6 to 31/6	Surface barrier transistors, figures in f_α column refer to maximum frequency of oscillation* or pulse repetition rates†
	SB 345	25—110	30—50*	−3	0·5	40	−5	100	27/6 to 39/6	
	SB 346	10 (minimum)	60—75*	−3	0·5	40	−5	100	36/6 to 53/-	
	SB 240	16— 30	20†	−3	0·5	25	−6	65	46/- to 66/6	
Tick No 232	2N 393	40—155	60 (average)	−3	0·5	50	−6	—	48/6 to 77/-	
	2N 597	35 (average)	4·5 (average)	−5	3	250	−30	—		
	2N 598	90 (average)	7·5 (average)	−5	3	250	−30	—		
	2N 599	105 (average)	18 (average)	−5	3	250	−30	—		

Germanium *n-p-n*, low power, high frequency transistors

Mullard Ltd.	OC 139		3·5 (minimum)	+5	3	100	+20	—	Price given on request	Symmetrical structures, suitable for switching circuits
Tick No 233	OC 140		4·5 (minimum)	+5	3	100	+20	—		

Germanium *p-n-p*, medium and high power transistors

Manufacturer	Type number	α'	f_α, Mc/s	V_c, volts	I_c, mA	P_c max at 25°C ambient (a) with infinite heatsink, (b) in free air	V_{cb} max, volts	Approximate cost	Remarks
Newmarket Transistors Ltd	V 15/20 IP	20—100	0·25 (average)	−1·5	20	(a) 2W (b) 0·5W	−15	12/– to 47/–	P_c max derating factor (a) 40 mW/°C rise in ambient temperature, (b) 10 mW/°C rise in ambient temperature.
	V 30/20 IP	20—100	0·25 (average)	−1·5	20	(a) 2W (b) 0·5W	−30		
	V 60/20 IP	20—100	0·25 (average)	−1·5	20	(a) 2W (b) 0·5W	−60		
Tick No 211									
	V 15/10 P	10— 20	0·1 (average)	−1·5	20	(a) 10W (b) 1W	−15	9/– to 60/–	P_c max derating factor (a) 200 mW/°C rise in ambient temperature, (b) 20 mW/°C rise in ambient temperature.
	V 15/20 P	20— 30	0·1 (average)	−1·5	20	(a) 10W (b) 1W	−15		
	V 15/30 P	38 (average)	0·1 (average)	−1·5	20	(a) 10W (b) 1W	−15		
	V 30/10 P	10— 20	0·1 (average)	−1·5	20	(a) 10W (b) 1W	−30		
	V 30/20 P	20— 30	0·1 (average)	−1·5	20	(a) 10W (b) 1W	−30		
	V 30/30 P	38 (average)	0·1 (average)	−1·5	20	(a) 10W (b) 1W	−30		
	V 60/10 P	10— 20	0·1 (average)	−1·5	20	(a) 10W (b) 1W	−60		
	V 60/20 P	20— 30	0·1 (average)	−1·5	20	(a) 10W (b) 1W	−60		
	V 60/30 P	38 (average)	0·1 (average)	−1·5	20	(a) 10W (b) 1W	−60		
General Electric Co. Ltd.	GET105	40— 90	0·6—1·1	−12	10	(b) 0·4W	−40	Price given on request	P_c max derating factor (b) 10 mW/°C rise in ambient temperature.
	GET110	40— 90	1·1 (average)	−12	10	(b) 0·4W	−40		
Tick No 212	GET115	40— 90	0·6—1·1	−12	10	(b) 0·4W	−15		
	GET116	40— 90	0·65—1·1	−12	10	(b) 0·4W	−30		
	GET120	40— 90	1·1 (average)	−12	10	(b) 0·4W	−30		
Mullard Ltd.	OC 16	16— 90	0·2 (average)	−7	300	(a) 24W	−16	Price given on request	P_c max derating factor (a) 600 mW/°C rise in ambient temperature
	OC 16R	16— 90	0·2 (average)	−7	300	(a) 24W	−32		
	OC 16T	16— 90	0·2 (average)	−7	300	(a) 24W	−32		
Tick No 213	OC 22	180 (average)	2·5 (average)	−2	400	(a) 13·5W	−24		P_c max derating factor (a) 280 mW/°C rise in ambient temperature
	OC 23	180 (average)	2·5 (average)	−2	400	(a) 13·5W	−24		
	OC 24	180 (average)	2·5 (average)	−2	400	(a) 13·5W	−24		
	OC 30	36 (average)	—	−7	100	(a) 6·5W (b) 1W	−16		P_c max derating factor (a) 130 mW/°C rise in ambient temperature
Semiconductors Ltd.	2N 600	70 (average)	7·5 (average)	−5	3	(a) 0·75W	−30	Price given on request	P_c max derating factor (a) 10 mW/°C rise in ambient temperature
Tick No 214	2N 601	105 (average)	18 (average)	−5	3	(a) 0·75W	−30		

Silicon *p-n-p*, low power transistors

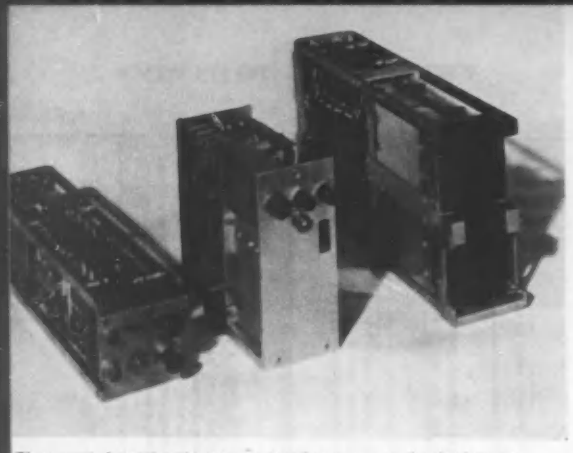
Manufacturer	Type number	α'	f_α, Mc/s	V_c, volts	I_c, mA	P_c max at 25°C ambient (a) with infinite heatsink (b) in free air	V_{cb} max, volts	A	Approximate cost	Remarks
Mullard Ltd.	OC 200	10— 60	0·3—3·5	−6	1	(b) 250mW	−25	30	Price given	Figures in f_α column refer to maximum frequency of oscillation
Tick No 215	OC 201	20— 80	4 (average)	−6	1	—	−25	30	on request	
Semiconductors Ltd.	2N 495	18 (average)	15 (average)	−6	1	(b) 150mW	−25	50	151/– to 190/–	
Tick No 216	2N 496	10 (average)	25 (average)	−6	1	(b) 150mW	−10	50	191/– to 242/–	

Silicon *n-p-n*, low power transistors

Standard Telephones & Cables Ltd. Tick No 217	TK 70A	30 (minimum)	4 (minimum)	+9	1	(b) 325mW	+30	—	Price given on request	
	TK 71A	10 (minimum)	1 (minimum)	+9	1	(b) 325mW	+30	—		
Texas Instruments Ltd.	2S001	10— 20	4 (average)	+5	1	(b) 150mW	+45	40	58/– to 77/–	
	2S002	20— 40	5 (average)	+5	1	(b) 150mW	+45	40	92/– to 123/–	
	2S003	20— 40	7 (average)	+5	1	(b) 150mW	+45	40	130/– to 173/–	
Tick No 218	2S004	40— 90	7 (average)	+5	1	(b) 150mW	+45	40	140/– to 187/–	
	2S005	45—150	30 (average)	+20	1	(b) 125mW	+40	50	155/– to 207/–	
	2S014	24— 55	20 (average)	+20	1	(b) 125mW	+40	50	125/– to 169/–	

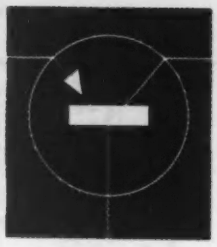
Silicon *n-p-n*, medium and high power transistors

Texas Instruments Ltd.	2S017	12— 36	0·2 (average)	30	30	(a) 4W (b) 1W	+60	138/– to 184/–	P_c max derating factor (a) 22·8 mW/°C rise in ambient temperature, (b) 4·6 mW/°C rise in ambient temperature
	2S018	12— 36	0·2 (average)	30	30	(a) 4W (b) 1W	+100	178/– to 235/–	
Tick No 219	2S012	10— 30	3·0 (average)	30	30	(a) 37·5W (b) 4W	+60	380/– to 507/–	P_c max derating factor (a) 150 mW/°C rise in ambient temperature, (b) 30 mW/°C rise in ambient temperature
	2S013	10— 30	3·0 (average)	30	30	(a) 37·5W (b) 4W	+60	290/– to 387/–	



Three naval electronic units using semiconductors, now under development

PART 2



Developments in components such as capacitors and resistors are matching the growing use of magnetic amplifiers and transistors in naval electronic amplifiers

Servo amplifiers for the Navy

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THE FIRST PART OF THIS ARTICLE, PUBLISHED LAST month, was mainly devoted to the thermionic a.c.–d.c. amplifier because it is the most common class of servo amplifier which has been used and continues to be used in the fleet.

Future trends in design

For high-power servos using Metadyne generators or hydraulic power amplification, the a.c.–d.c. amplifier is still necessary. However, with the introduction of transistors and the improved availability of 2-phase induction servomotors, the a.c.–a.c. amplifier is becoming much more popular for low-power servos.

The temperature dependence of transistor parameters leads to difficulty in amplifying d.c. signals without excessive drift problems, and most transistor servo amplifiers built to date have been designed to drive a.c. motors. At the same time the use of split-field motors offers certain other advantages and it is by no means impossible to build a.c.–d.c. transistor amplifiers.

The more important practical features to be considered in choosing between a.c. and d.c. motors are listed below.

Factors favouring the d.c. split-field motor

1. An appreciable power gain is provided in the d.c. motor since the power to be supplied to the split-field winding is only a small fraction of the total power input. With an a.c. motor one-half of the total power input must be supplied by the output stage of the amplifier. As a result the output stage must handle less power when driving a d.c. split-field motor, for a given mechanical shaft output.

2. A given a.c.–d.c. amplifier may drive any one of a range of 80 mA (or 50 mA) motors of different sizes, whereas the corresponding a.c.–a.c. amplifier output stage can drive only one size of motor. The latter can be overcome if motors are 'padded' or 'tuned' to appear as a standard resistive value at the signal frequency, but the output stage of the amplifier must then be capable of handling the power corresponding to the largest motor in the range.

3. Shaping networks such as the very common phase-advance or pre-retardation networks can be used conveniently with the signal in the form of a direct voltage. Phase advance of the envelope of an a.c. signal without affecting the carrier can be arranged with a notch filter but only if the supply frequency is closely controlled, at least at the higher frequencies such as 400 c/s.

4. Velocity or transient velocity feedback terms can be derived from d.c. tachogenerators and injected into the d.c. end of an a.c.–d.c. amplifier: a.c. tachogenerators

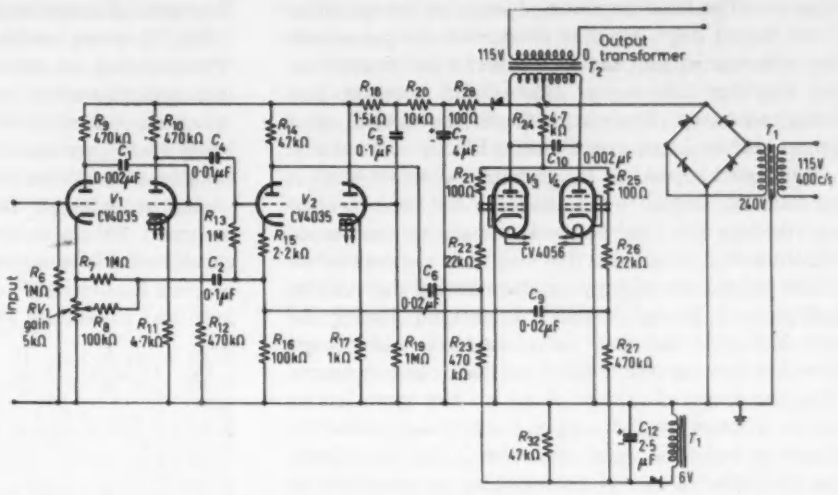


Fig. 11 Simplified circuit of Mark 4AC 400 c/s a.c.—a.c. valve amplifier

produce much smaller outputs than d.c. types (typically down by a factor of 50 or 100). If d.c. tachogenerators are used with a.c. motors, a modulator is necessary in order to get the feedback term into a form suitable for injection into the amplifier.

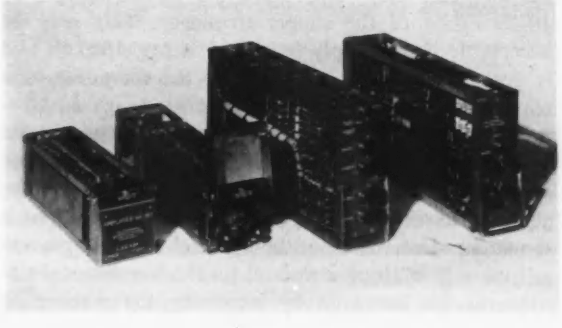
5. A wide range of 80 mA split-field motors is readily available in this country, whereas this has not been true for a.c. motors. This is not serious since a.c. motors are now becoming available in a range of sizes and for both 400 c/s and 60 c/s. Power outputs are unlikely to be as great as those of the d.c. motors at the top end of the range for some time to come, so that medium-power servos (between the instrument class and the RPC types) will certainly continue to use d.c. split-field motors for the present. A typical example of a medium-power servo might be an Asdic transducer bearing drive.

6. An output transformer, which may be rather bulky if the frequency is 50 c/s or 60 c/s, is usually necessary with a.c. servomotors controlled by thermionic amplifiers. (When suitable motors become generally available transistor servo amplifiers will make the output transformer unnecessary.)

Factors favouring the two-phase a.c. induction motor

1. The a.c.–a.c. amplifier is generally much simpler because of the absence of the phase-conscious rectifier.

Fig. 12 Modern miniature naval servo amplifiers



2. Because there are no d.c. stages the drift problem is eliminated. This facilitates the use of transistors and avoids the regular balancing necessary with most a.c.–d.c. amplifiers.

3. The resistor used with the armature of the d.c. motor and the need for a d.c. supply for the armature (commonly 220 V) are eliminated. This results in a saving of power and reduced heat dissipation, and the size of the output transformer in an a.c. system is more than compensated by the absence of a resistor box.

4. Maintenance and interference are reduced by the absence of the commutator.

Field and armature control

Comparing the above advantages and disadvantages one realizes that there is a quite large class of simple, low power, moderate performance servos to which the a.c. motor is well suited. If a motor with a built-in a.c. tachogenerator is used and if velocity feedback can give the required performance, the amplifier can be very simple and compact.

So far only field control of the d.c. motor has been mentioned. Another method of control which is suitable for any d.c. motor—but particularly the new permanent magnet motors—is that of armature control. However, this is not suitable for use with thermionic amplifiers with their high-voltage/low-current characteristics. With magnetic amplifiers and transistors the method of control may prove profitable. The main drawback is that the motor armature presents a two-terminal load to the amplifier and this makes a loss of efficiency unavoidable in the amplifier output stage in order to give a reversible output.

A 400 c/s a.c.–a.c. amplifier

The circuit shown in Fig. 11 represents a simplified version of a self-contained 400 c/s a.c.-a.c. instrument-type servo amplifier (Mark 4AC). The built-in test facilities have been omitted in order to simplify the

diagram. The most interesting feature of this amplifier is the output stage, which in effect works on the switching principle so that the rectifiers can be included on the amplifier chassis, no external h.t. supplies then being necessary. The circuit forms the subject of a patent held by Lancashire Dynamo Electronic Products.

The signal applied to the grids of the output stage is a.c. and the supply to the anodes is full-wave-rectified a.c. through the centre-tapped primary of the output transformer. Current can flow only in a particular half of the output transformer primary during the positive half-cycle of the signal applied to the grid. During the next half-cycle the other valve conducts, and current flows through the other half of the transformer primary. Thus the output of the secondary is a sine wave and its phase, relative to the supply, is reversed when the signal applied to the grids is reversed. The h.t. supply for the earlier stages of the amplifier is smoothed by capacitors C_5 and C_7 and R_{20}, and MR_1 prevents the capacitors discharging back into the output stage. The right-hand half of V_2 is used to reduce jitter caused by h.t. variations. The amplifier gain control is achieved by variable negative feedback over the early stages of the amplifier.

The Mark 4AC amplifier is intended for use where a tachogenerator is available to give a velocity feedback term. The velocity lag introduced by this method of stabilization may not always be acceptable, but it can be cancelled by fitting a tachogenerator to the shaft of the element controlling the servo and using a velocity feed-forward term.

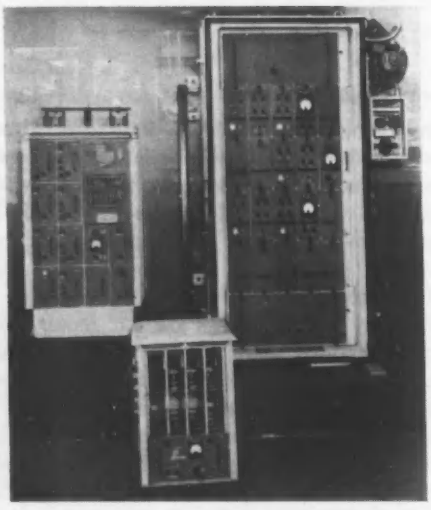


Fig. 13 These typical naval amplifier assemblies contain amplifiers and auxiliary units

The amplifier is constructed on a chassis roughly 3 in. × 2½ in. × 13 in. long, the valves are all flying-lead types mounted on a block which is conduction cooled by clamping the amplifier to a metal surface, and in the final version rectifiers to allow coarse and fine synchro signals to be mixed are included on the chassis (these are not shown in Fig. 11).

Examples of actual equipment

Fig. 12 shows a selection of modern servo amplifiers. The two units on the left are Mark 19F 400 c/s a.c.–d.c. general-purpose amplifiers which can deliver a maximum output of 50 mA. This latter figure is now being used in preference to the old figure of 80 mA and suitable motors and Metadyne generators are being wound accordingly. The unit on the right is an all-magnetic 400 c/s a.c.–a.c. instrument servo amplifier capable of driving motors up to Size 18. The remaining unit is a four-channel 'data set' unit, which is a special unit used to indicate that servos have in fact run into line.

Fig. 13 shows three amplifier assemblies of different types, the upper two being cooled by forced air ventilation; the small cubicle shown without its unit normally contains magnetic amplifiers of the type shown in Fig. 12 and does not require a fan.

Two-channel control systems

In order to increase the overall accuracy of a servo system it is common practice to provide two channels of control—a coarse channel in which there is one-to-one coincidence between the shaft driving the error-measuring element and the controlled element, and a fine channel in which the shaft driving the error-measuring element is geared up with respect to the controlled element. With single-channel control the accuracy of the error-measuring element determines the limits of accuracy of the system, but with a two-channel system this limit on the accuracy is improved very nearly by the order of the gear ratio (owing to the errors introduced by the gear box the improvement is not exactly equal to the gear ratio).

For high-inertia systems it is usual to have a coarse amplifier incorporating a coarse/fine change-over system which determines the exact point of changing over control from the coarse to the fine channel. For instrument-type servos the non-linear characteristics of metal rectifiers are used.

Magnetic servo amplifiers

As mentioned earlier, the conventional types of magnetic amplifier are not in general suitable for use in servos because of the rather slow response to changes of signal. The time-constant is roughly proportional to the power gain but at average values of power gain the amplifier may introduce a lag which is typically 10–20 cycles of the supply frequency. This may be acceptable if the supply frequency is say, 1600 c/s and is perhaps tolerable at 400 c/s if the servo response required is not too snappy. The servo design is, however, made simpler if these lags can be reduced and the 'flux resetting' magnetic amplifiers or special variations of the 'conventional' types are usually preferred. Before going on to consider these more sophisticated designs it should be mentioned that the figure of merit, expressed as (power gain)/(time-constant) for the conventional circuits can be improved by increasing the number of

stages. This follows from the fact that the time-constant of a single stage is proportional to the power gain, and that power gains for several stages are multiplicative whilst lags are additive. There is a limit to the improvement obtainable by this method because of the difficulty of avoiding instability of multi-stage magnetic amplifiers arising from interaction of stages through the power supply impedance. In one four-stage amplifier (not a servo amplifier) it proved necessary as a last resort to use a separate exciter for two of the stages to cure the instability.

The boost-buck series self-excited amplifier

It is possible to design magnetic amplifiers to have response times which are appreciably better than those of the ordinary conventional type without going to the flux-resetting class. Once the technique is established they are probably more straightforward to design than the flux resetters and although the figure of merit is not as good as the latter, the easier design work may in some instances make them preferable. One such circuit is known as the boost-buck series self-excited magnetic amplifier. It can be used only as a push/pull device and its chief advantage is its relative insensitivity to push/push conditions, such as result from supply variations, while retaining its sensitivity to push/pull signals. It is possible to achieve time-constants down to one cycle by careful design, at the same time obtaining worth-while power gain.

Two such stages followed by a flux-resetting output stage were used in one a.c.–a.c. servo amplifier where the dynamic performance requirements were quite severe.

The circuit of the boost-buck amplifier is illustrated in Fig. 14, from which it will be seen that there are two feedback windings on each core instead of one as in an ordinary series self-excited type. The winding which corresponds to the normal positive feedback winding in the ordinary case is the 'boost' winding and the other, referred to as the 'buck' winding, is connected in series with the boost winding on the opposite side. To a push/pull signal the buck windings act as positive feedback and increase the gain, but to push/push signals the effect is that of a negative feedback, thus reducing the sensitivity to supply fluctuations.

A practical snag is that separate load and self-excitation rectifiers are found to be advisable and a single push/pull stage requires four bridges or 16 individual rectifiers.

Flux-resetting and fast response

Fast-response magnetic amplifiers were described in some detail in an article by Frost-Smith in the October 1958 issue of CONTROL, so that they will be discussed only briefly here. The flux-resetting principle, first described by Ramey in 1951, has since proved the basis of very many variations which are so numerous that it is impossible even to mention them all in this article. Each has its own particular advantage for a given application, and circuit designers often have their own variations on a particular circuit.

The half-wave bridge-connected magnetic amplifier was described in an AIEE paper in May 1952 by Lufcy, Schmid and Barnhart of the US Naval Ordnance Laboratory. It is a half-wave sign-conscious fast-response amplifier having only two cores with a minimum of four windings on each. The load is in effect connected across a bridge whose four arms are the four a.c. windings of the two cores, and a resistor is necessary in order to avoid short-circuiting the power supply when both cores are saturated simultaneously. The controlling signal may be either d.c. or modulated a.c. with the carrier derived from the same supply as the excitation and in phase with it, e.g. a Magslip or synchro signal.

The output of this half-wave circuit contains a d.c. term which in a.c.–a.c. servo amplifiers may be useful in producing damping in a two-phase induction motor, but it can also be a disadvantage because of the additional heating in the motor. This direct current may be relatively high because the d.c. resistance of the motor

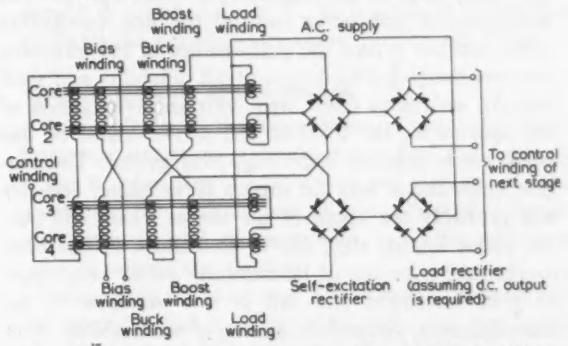


Fig. 14 The boost-buck series self-excited magnetic amplifier has two feedback windings on each core

is very much less than the impedance at the signal frequency of, say, 400 c/s. If a 115 V supply to the amplifier is used the fundamental component of the output to the motor must be somewhat less than 115 V. A full-wave circuit can be arranged, in which case the output voltage is higher and the d.c. component is no longer present.

The power gain of the Lufcy amplifier is rather less than that of the Ramey type. The maximum response time is one cycle for a single stage and an extra half-cycle for each additional stage.

One of the most promising flux-resetting amplifier circuits published to date is that developed by House of the US Naval Research Laboratory and announced in 1955. As with other magnetic amplifiers described by Geyger and Scorgie, it was originally developed from ring-modulator circuitry. It has several variations including series-feed and parallel-feed control, but basically it gives half-cycle response, has a full-wave output, and is sign conscious. It gives a comparatively high power gain per stage and a.c. or d.c. control may be used. Fig. 15 shows a circuit for the series-feed version.

Valve-driven magnetic power-handling stages offer

an attractive alternative to valve output stages, since they greatly simplify the problem of cooling the output stage. Most of the heat to be dissipated in a thermionic amplifier is usually in the output stage. Valve-driven magnetic amplifiers are somewhat easier to design than multi-stage magnetic amplifiers. The Ramey circuit is particularly easily controlled by inserting a pentode in the control circuit.

For the future, transistor-driven magnetic amplifiers will undoubtedly find considerable application until such time as high-power transistors become more readily available, but eventually it would seem that all-transistor servo amplifiers will largely replace magnetic servo amplifiers.

Transistor servo amplifiers

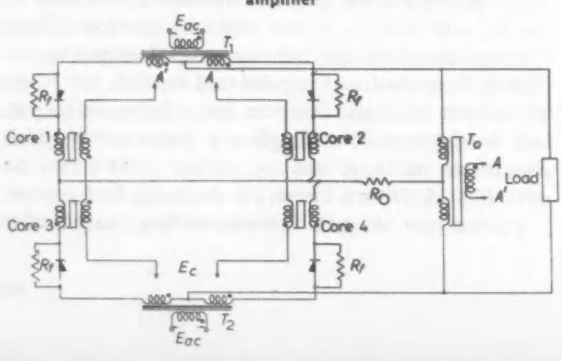
As discussed in other articles in this issue, transistors offer a number of important advantages over thermionic valves, the most valuable one for naval electronic equipment probably being the greatly improved reliability and life. This had been predicted confidently in the very early days of the transistor ten years ago but was unfortunately not borne out by the first production types, and for a time the performance of the transistor was overshadowed by doubts about reliability and shelf life. An enormous effort went into an investigation of the reasons for the troubles and in the course of this work much valuable knowledge was gained. The biggest single factor was the ingress of moisture, and this was probably the origin of the stories which still persist about limited shelf life of transistors. It has been overcome by the use of hermetically sealed metal cans or glass envelopes and this is now standard to all manufacturers. Secondary causes of unreliability were tracked down to inadequate control of impurities and contamination during manufacture, and this, too, has been dealt with.

Transistor life

Modern transistors used in properly designed circuits can be expected to be extremely reliable and to have very long lives. The importance of careful circuit design cannot be overestimated, because the transistor with its small mass and very short thermal time-constant cannot be subjected to overloads for even very short periods without risk of permanent damage or immediate failure. In the past insufficient care in designing valve circuits has often been masked by the fact that valves can be overloaded without immediately obvious effects, and the valve has been blamed for troubles really caused by weak circuit design. Life test data in this country are not very plentiful but a great deal of information has been amassed in the USA. Conclusive results must, of course, take a long time to obtain—10,000 hours life requires nearly 14 months of continuous running—and accelerated life tests are difficult to evaluate, but without being over-optimistic it is fair to say that the earliest predictions are now coming to fruition.

The definition of life of a transitor is not an easy matter since it will often depend on the requirements of the circuit. The early catastrophic failures experienced with valves are very much less in transistors and end-of-life will have to be defined in terms of the change of important parameters such as current gain, noise factor, and collector cut-off current. One circuit may be able to tolerate much larger changes than another. In general the sort of figures aimed at and likely to be attained are of the order of 50,000 to 100,000 hours for industrial, and 20,000 to 30,000 for domestic and entertainment, equipments.

Fig. 15 The series-feed version of the House-type magnetic amplifier



Other advantages

The other advantages of transistors can be mentioned only in the briefest terms here but they include small size and weight, excellent resistance to shock and vibration, high circuit efficiency, absence of heaters, low voltage requirements, and instant operation on switching on. On the other hand the disadvantages include the limited high frequency and high power performance, temperature limitations, spread of parameters in production, the loading of the input by the output circuit, the absence of an overload margin, and the difficulty of obtaining drift-free d.c. amplification. For low frequency equipment in naval ambient temperatures (55°C max.) these limitations can be overcome or allowed for in various ways.

In the USA many servo amplifiers using transistors or a combination of transistors and magnetic amplifiers have been constructed, mainly for use in airborne or vehicular equipments. The Admiralty is conducting a comprehensive programme of work in applying transistors to electronic equipment.

A transistorized output stage

A useful output stage, which gives power amplification combined with almost drift-free phase-conscious rectification, deserves attention and will be briefly discussed. The circuit has been described by an American, De Sautels.

The half-wave version is shown in Fig. 16a and the full-wave type in Fig. 16b. The components can if desired be rearranged to allow the collectors of the two output transistors to be connected together and earthed. This permits the cases of the transistors, which are electrically common with the collector, to be placed in direct contact with a heat sink without the use of a mica insulating washer. The latter has a pronounced

effect on the permissible power dissipation within the transistor, reducing it by a factor of anything from 2 to 6 times.

In Fig 16a, let the signal be in such a sense that points A and B are in phase, and consider the half-cycle in which both are negative. The negative voltage applied to the base turns the transistor on and current flows in one half of the load L_1 via rectifier MR_1. The windings on transformer T are connected such that C is opposite in phase to B so that MR_2 is not conducting and no current flows in the other half of the load L_2. In the next half-cycle the transistor is cut off and no current can flow in either half of the load.

If now the signal phase is reversed relative to that of the supply, current flows in L_2 only during the half-cycle when A and C are both negative. Note that load current flows in different half-cycles of the supply according to signal phase. The emitter resistor R_e improves the performance with temperature variation and makes interchangeability of transistors simpler, i.e. the circuit is less dependent on the parameters of individual transistors. In practice the full-wave version of the circuit would be used in most cases and the operation of this form will be clear from Fig. 16b.

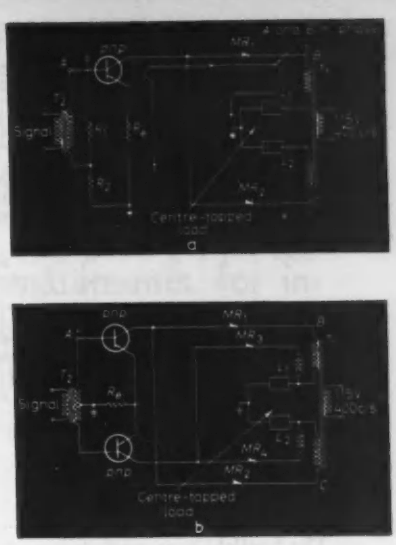


Fig. 16 (a) Half-wave rectifying transistor output stage; (b) Full-wave rectifying transistor output stage

400 c/s a.c.–a.c. transistor servo amplifier

The circuit shown in Fig. 17 represents a 400 c/s a.c.–a.c. transistor servo amplifier capable of driving induction motors up to Size 18. It is intended for use where an a.c. tachogenerator is available for the provision of stabilizing term, and the output transformer T_4 is only necessary if it is desired to drive standard 57/115 V motors. If low-voltage motors such as are now becoming available are used, the output transformer can be dispensed with.

The pre-amplifier includes two stages each consisting of an OC72 transistor with temperature stabilization and an overall negative feedback to compensate for differences between transistor parameters. The OC72 phase-splitter is transformer-coupled to a Class B driver stage consisting of 2 GET5 transistors. Negative feedback is introduced into the driver stage by unbypassed emitter resistance. The driver stage is transformer-coupled to the output stage, which consists of a pair of OC16's working in Class B. The output stage and the driver stage are both fed with full-wave-rectified a.c. and the bias supply for the pre-amplifier and phase splitter is generated internally within the amplifier.

Two voltage reference diodes and a GET5 transistor provide a stabilized supply for this purpose. All rectifiers are silicon junction types.

The output stage is very efficient because of the mode of operation, and the overall efficiency of the amplifier is about 80%. The output stage can deliver up to 20 W to the primary of the output transformer. As the latter has an efficiency of the order of 90%, up to 17 W is available to feed the control phase of the motor and 1 W is available to power the output indicator lamp. The supply to the reference phase of the motor is also derived from the mains transformer, the necessary phase shift being obtained by including a capacitor in series. The use of an a.c. tachogenerator could be avoided by using a notch filter at the front end of the amplifier provided that the frequency stability of the power supply is within, say, ±1%. In practice it would then probably be necessary to add a further a.c. stage.

New components and techniques

In parallel with the introduction of magnetic amplifiers and transistors a tremendous effort has been devoted to improving the reliability and stability of other electronic components and to producing new components which lend themselves to use with techniques such as potting and printing.

In general the trend has been towards improvement of reliability and stability as the main aim, but accompanied by miniaturization and the ability to operate in more severe environmental conditions, especially higher temperatures.

Changes in electrolytic capacitors

Notorious for its record of poor reliability compared with other components in the past, the electrolytic capacitor has been avoided as far as possible in recent naval equipments. The chief reason for the poor working life and shelf life of the ordinary electrolytic capacitor is a small but signficant chemical action of the electrolyte on the electrodes. The more modern etched-foil types are appreciably better in this respect than the earlier plain foil ones.

In the tantalum electrolytic capacitor this action is non-existent because of the inert nature of the metal tantalum, and the unit can be hermetically sealed because of the very low rate of gas formation. Working voltages are normally lower but this is no disadvantage in transistor circuits. Space factor is extremely good as will be shown by the following, which takes a 100 V paper capacitor as a standard for comparison:

Metallized paper	65% volume
Ordinary electrolytic	23% volume
Tantalum electrolytic (foil types)	15% volume

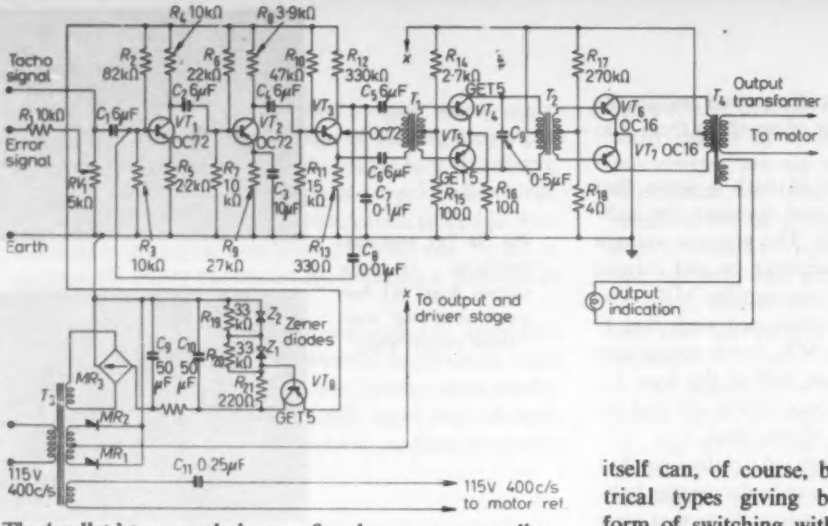


Fig. 17 Simplified circuit of a 400 c/s a.c.—a.c. transistor amplifier

The ' pellet ' type made by one firm has an even smaller volume and can be used up to 125°C compared with 85°C for the foil type.

Another capacitor designed especially for good stability is the plastic dielectric type. It has a very small temperature coefficient but its maximum temperature limit up to now is only 60°C. A range of tantalum capacitors approved for Service use is given in RCL 134B and of plastic dielectric types in RCL 137. P.T.F.E. has been used for capacitors to work up to 200°C.

New resistors, rectifiers and relays

A variety of new resistor types has been announced by different manufacturers in recent years, including metal and oxide film types, glass fibre types, and others for special purposes. In the Fiberloy glass fibre type the resistance element consists of a glass fibre, on whose surface a film of precious metal has been deposited, wound upon a high-thermal-conductivity ceramic former. The oxide film resistors have been particularly successful; they exhibit the advantages of the ordinary wire-wound types but cover a wider range of resistance values. It is possible that they may eventually supersede the present Grade 1 carbon resistors.

Rectifiers have in the past been somewhat suspect as regards reliability, especially when operated in high ambient temperature conditions. A range of high-temperature selenium rectifiers capable of working up to temperatures of 85°C has been available for some time now. Silicon junction rectifiers should inherently be more reliable than selenium types when used in high ambient temperatures; they have very much lower reverse currents and incremental forward resistances. On the other hand silicon rectifiers are very sensitive to overvoltage and surge currents, and it is vital to ensure that the specified ratings are not exceeded with any adverse combination of circuit and supply conditions.

Relays have in the past also been a potential source of trouble but this has been largely overcome by more recent designs, usually in hermetically sealed cans. Subminiature relays are also now becoming available in this country, and their size matches the miniaturization which can be achieved with transistors. The transistor itself can, of course, be used as a switch, the symmetrical types giving bi-directional facilities. Another form of switching with no moving parts is offered by saturable cores, sometimes known as *magnetic logic units*.

Plugs and sockets have been successfully miniaturized and a wide variety of types is now available in this country. Use of wrapped-wire joints as an alternative to soldered joints is also beginning to find application.

The many other new developments in electronic components are too numerous to even mention in this article but there is every indication that by the time transistors come into general use there will be a comprehensive range of components enabling full value to be obtained from their use.

Conclusion

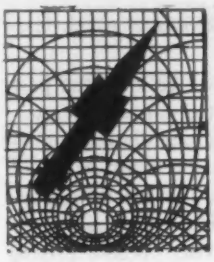
The servo amplifiers dealt with in this article have all been of the class in which there is a range over which the output varies linearly with the input before saturation is approached. An important group not mentioned is that which includes amplifiers for ' bang-bang ' servos, in which the output at any particular instant is either zero or maximum in one direction or the other. They have not found much use in the fleet to date but may well find more use in the future, perhaps using the transistor in its capacity as a near-perfect switch.

Looking some distance into the future we can see that the use of servo amplifiers in the electromechanical analogue computing field will probably diminish as a result of a wider interest in digital computers. Many digital computers which were not practical with thermionic valves because of power consumption, cooling problems, and unreliability, can be built successfully with transistors, which enable lightweight compact computers to be constructed. Already in the USA fire control and flight control systems for aircraft have been built using transistor digital techniques and tested with marked success. Digital techniques are of course not ideally suited to every type of problem requiring solution and it remains to be seen whether they can usefully be applied to naval fire control computers.

Acknowledgments

We wish to express our appreciation of the assistance in preparing this article given by our colleagues in the Electrical Engineering Division of the Ship Department of the Admiralty.

The Mark 14F amplifier was developed by the Admiralty Engineering Laboratory (Electrical Department), West Drayton, the Mark 4AC amplifier by Lancashire Dynamo Electronic Products, and the transistor amplifier by Metropolitan-Vickers. We also wish to thank the Director of Electrical Engineering, Admiralty, for permission to publish this article.



CONTROLLING GUIDED MISSILES—3

More reliable instruments for industrial use will be among the fruits of present military development

Transducers for G.W. research

by **M. A. PERRY**, D.C.AE., GRAD.I.MECH.E., A.F.R.AE.S.
College of Aeronautics, Cranfield

OVER THE PAST DECADE THE NEED FOR MAKING MEASUREments by electrical methods has become increasingly important. One reason for this is the ease with which a signal that is an electrical analogue of the physical quantity measured may be modified; e.g. by filtering, integrating or differentiating. It can also be easily transmitted over a link to a remote point for control or recording purposes.

Electrical transducers

Devices which provide suitable signals from the physical quantities are known as *electrical transducers*, and the requirements of guided weapon research have led to the development of many varied types.

Transducers fall into two groups, *active* and *passive*. The proposed BS definitions* of these groups are as follows:

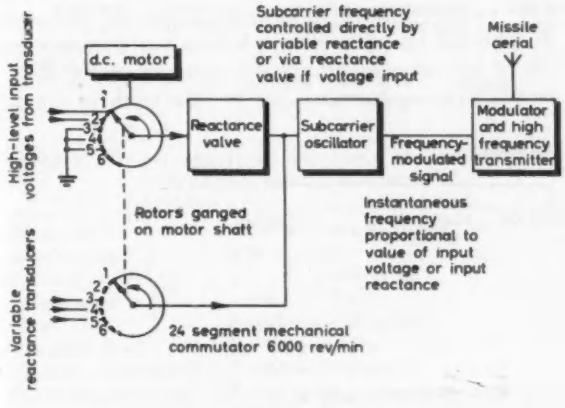

Subcarrier frequency controlled directly by variable reactance or via reactance valve if voltage input
Missile aerial
d.c. motor
High-level input voltages from transducer
Reactance valve
Subcarrier oscillator
Frequency-modulated signal
Modulator and high frequency transmitter
Rotors ganged on motor shaft
Instantaneous frequency proportional to value of input voltage or input reactance
Variable reactance transducers
24 segment mechanical commutator 6000 rev/min

Fig. 1 Basic time-multiplex telemetry system

Active transducer. A transducer such that the energy it transmits to the second system is derived, at least in part, from sources other than waves it receives from the first system.

Passive transducer. A transducer whose output waves are independent of any sources of power and which are controlled by the actuating waves.*

Thus a self-generating type of transducer like a solar cell is a passive transducer, whereas a capacitive pick-off is an active transducer. Table 1 shows some common methods used in electrical transducers to detect a change in the physical quantity.

'Finesse'

Many physical quantities can be converted by means of a primary detector into a displacement, and the measurement of small displacements with great *finesse* is the basic design principle for many instruments. The finesse of a particular transducing technique is a measure of the reaction of the transducer on the quantity it is measuring.

Closed-loop devices

A linear input-output relationship is desirable to avoid calibration difficulties but some system may be inherently non-linear. In the 'open loop' transducer this is accepted, but by combining the transducer with a feedback amplifier and forming a closed loop device linearization and stability of calibration are achieved. The 'closed loop' transducer and instruments using force-balance principles are becoming more important with the increase in the precision required for making measurements by electrical methods.

*For the revision of BS 204—given in a private communication

Rugged and reliable

A characteristic of most transducers which must be minimized when they are designed for missile applications is their susceptibility to varying parameters other than that which they are measuring. The environmental conditions of the missile will almost certainly be worse than the 'laboratory conditions' which some instrument specifications assume. Acceleration forces of several *g*, pressure drops equivalent to a change in altitude of 50,000 ft, and temperature changes of a few hundred degrees Centigrade are not uncommon. Not surprisingly most guided missile transducers must be made rugged and as reliable as possible. Instrument failure cannot be tolerated.

The success of an expensive trials programme relies on the ability of the transducer and its associated equipment to function under the most adverse missile behaviour. In such trials the instrumentation is not often recovered. This is usually for economy and because of the type of firing range employed (although probably ballistic missile instrumentation for re-entering vehicles will demand recovery owing to communication difficulties from a re-entry nose cone during flight). Radio telemetry must be used and the transducer will generally be chosen for its suitability for use with such a telemetering system. The following factors must all be taken into account in making this choice:

Ease of calibration	Linearity	Reliability
Compatibility with telemetry	Physical size	Repeatability
Finesse	Range	Resolution
Hysteresis	Relative sensitivity to other effects	Response
		Ruggedness

Instrumentation for flight trials of guided missiles

Before discussing some transducers used in missile research, I shall outline the type of inputs which telemetry senders require.

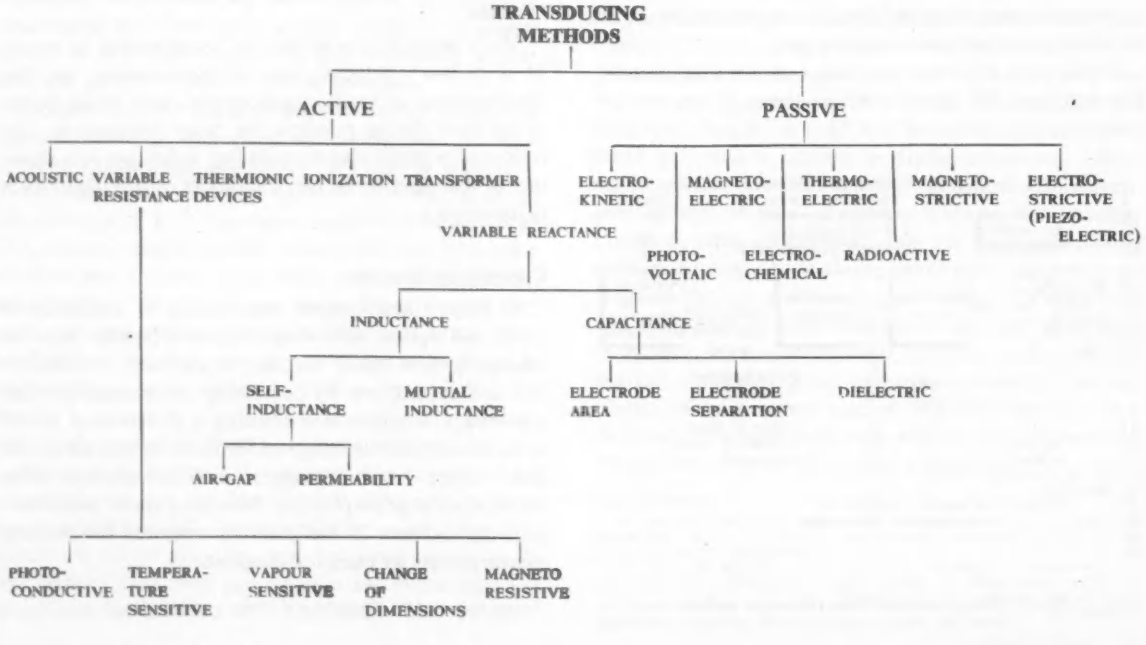
The basic time multiplex system used over the past few years has a frequency-modulated carrier for intelligence transmission. This frequency modulation is produced either by a high-level voltage input or by a variable reactance as shown in Fig. 1, these being provided by the transducer. Many typical g.w. transducers have been tailored to fit this system. Where this is impossible, for instance with low-level (millivolt) outputs from strain gauge bridges or thermocouples, special pre-circuits are necessary to raise the transducer output to a level suitable for telemetry.

The rate at which the measured quantity may be faithfully reproduced is a function of the transducer, pre-circuits and the telemetry system, but a discussion of the relative merits of different telemetry systems is outside the scope of this article. I shall tacitly (perhaps tactfully) assume that the telemetry designer can provide a system capable of handling the dynamic range of the measurements as required.

This range extends from zero frequency to several thousand cycles per second. Therefore if the transducer behaves dynamically as a simple second-order system with velocity damping it must have a high natural frequency and optimized damping. In turn this means a system with a high stiffness/mass ratio, i.e. one which is mechanically relatively insensitive; thus there is a need for detecting small displacements in many types of transducer. The maintenance of optimum velocity damping is often imperative if transients are to be reproduced accurately with only a simple time delay.

Table 2 indicates the nature and range of some of the quantities to be measured in flight trials.

TABLE 1



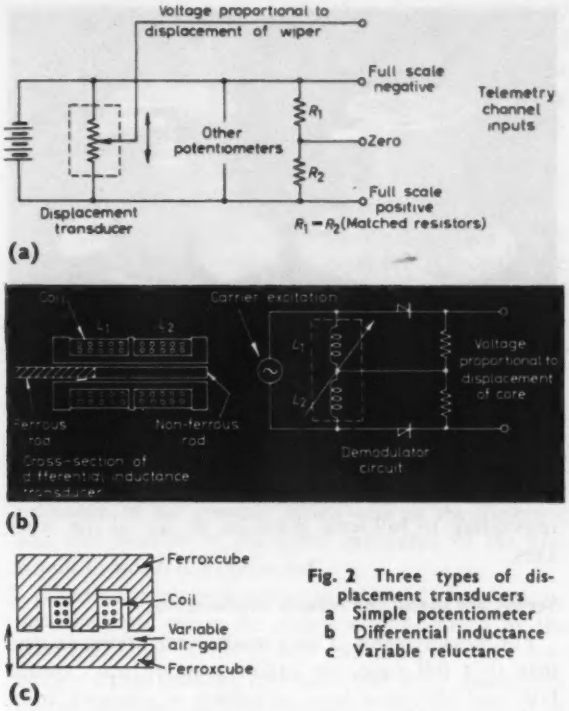


Fig. 2 Three types of displacement transducers
a Simple potentiometer
b Differential inductance
c Variable reluctance

The measurement of displacement

Where it is necessary to measure large displacements —for example, actuator stroke, control position, fuel valve position—a rectilinear or rotary potentiometer usually satisfies the requirements of resolution and range (see Fig 2a).

However, potentiometer pick-offs—even though they may have a life of a million cycles—must be used with caution. Unless the potentiometer is properly designed the vibration environment of the missile will have a detrimental effect on the contact between the wiper and the potentiometer element.

Nevertheless the overwhelming advantage of a high-level voltage output and the resolution possible with present-day winding techniques (using 0·0005 in. diameter wire) have led to the adoption of the potentiometer in many other forms of transducer where it measures the displacement of a primary detector. The resolution is not limited by the practical difficulty of winding wire less than 0·005 in. in diameter but by the ability to draw wire of this order of gauge thickness with a constant cross-section. Failure to do this results in a non-linear potentiometer. Another advantage of the potentiometer is that if the supply voltage is transmitted as a reference the accuracy of the system is not affected by battery voltage changes during flight, since the measurement of displacement is in the form of a ratio.

Small potentiometers normally operate over the temperature range −50° to +70°C and have a comparatively long life but development of short-life types has reached a stage where a life of several minutes is possible at 200°C. Carbon-track potentiometers are seldom used since their stability is poor compared with a wire-wound potentiometer using silver/palladium or Nichrome wire.

TABLE 2 TYPICAL QUANTITIES AND RANGE OF MEASUREMENTS IN GUIDED MISSILE RESEARCH

Displacement	0·0001 in.—several inches
Acceleration	0·001*g*—1000*g*
Pressure	1 lb/in²—10,000 lb/in²
Temperature	−150°C—1700°C
Flow	0·1 gal/min—100 gal/min
Vibration levels	1*g*—500*g* 10 c/s—8 kc/s
Angular acceleration	5 rad/s²—2000 rad/s²
Sound pressure level	Up to 200dB in frequency range 5–25 kc/s

Differential inductance transducer

For very severe environmental conditions it will probably be necessary to use the differential inductance type of pick-off shown schematically in Fig. 2b. This achieves infinite resolution with complete freedom from sliding contacts and can have a linear output for several inches displacement of the core. In order to obtain a voltage output however one must supply carrier excitation to the bridge system and demodulate this as shown in the diagram.

The differential inductance transducer can measure large or small displacements and is mechanically and electrically robust. It is moisture proof, relatively insensitive to temperature effects and has no mechanical friction. Furthermore the length of cable between the transducer and the pre-circuit is fairly unimportant. Inductance transducers of this type have been designed for temperatures of 700°C. The coils are wound on a stainless steel tube and then covered with a ceramic. Electrical connexions are made with silver welded studs.

The dynamic response of the potentiometer in small instruments is limited by wiper bounce at around 20 c/s. This is inevitable if the friction in the system due to wiper contact pressure is to be kept as low as possible so as to avoid non-linearities. The differential inductance transducer however is limited only by the carrier excitation frequency. This frequency usually lies in the range 400 c/s–3000 c/s and the instrument may be used dynamically up to one-fifth of the excitation frequency chosen.

Variable reluctance transducer

One of the common transducing elements in use in missiles is the variable reluctance type shown in Fig. 2c. The transducer has an E- and I-bar arrangement of magnetic material and the reluctance of the circuit is changed by moving the I-bar relative to the E-core. The total range of movement is 0·010 in. The coil in the centre limb forms a frequency determining element in the telemetry subcarrier oscillator. Variation of its inductance by the I-bar therefore produces frequency modulation of the signal direct; provided precautions

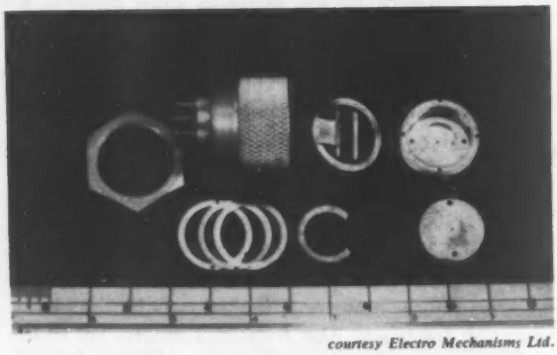
are taken over the stability of the other components in the oscillatory circuit a highly sensitive detector is formed.

Since the subcarrier frequency is high (150 kc/s) and the inductance required is only a few millihenrys the transducer is physically small. The core is of low-loss Ferroxcube material and has overall dimensions of 0·5 × 0·4 in. The transducer has a high finesse and the size of the I-bar which has to be attached to the primary detector does not usually increase the latter's mass significantly.

The measurement of acceleration

The inductance transducer can be turned into a very robust linear accelerometer by using the principle of displacement measurement to detect the deflexion of a spring mass system. Fig. 3 shows a typical acceleration transducer. This must either measure the boost phase acceleration, which may be of the order of 30*g*, or withstand this acceleration as an overload in order to measure full scale 1–2*g* for accelerations and decelerations occurring later in the flight. The armature can be fitted with stops to restrict its movement, and initial adjustments can be made to allow for any ratio of expected positive to negative acceleration in the whole range.

The achievement of the optimum value of velocity damping force for transient measurements over the temperature and altitude range in transducers of high



courtesy Electro Mechanisms Ltd.

Fig. 3 This inductance acceleration transducer uses an I-bar and mass on a cantilever spring system

natural frequency is often difficult. Silicone oil damping is nearly always employed even though its temperature characteristics are not ideal, since oil damping gives the highest damping force for a given weight or volume. Where precise damping is required the tendency is to use eddy currents, but the physical size of the magnet assembly is sometimes prohibitive and the damping force that can be achieved is quite small, restricting its use to low range accelerometers.

One further object in the design of an accelerometer is the reduction of cross-sensitivities to less than 1% when the instrument is subject to an acceleration corresponding to full-scale deflexion in one of the other axes.

courtesy Electro Mechanisms Ltd.

Fig. 4 Exterior and cut-away views of a lead zirconate piezoelectric vibration transducer showing preloading mass

Servos are useful for minute accelerations

For measurements of very small accelerations, i.e. less than 0·1*g* full scale, the ordinary spring mass system fails and the open loop transducer is replaced by a servo system using force-balance principles. One such instrument is essentially an angular accelerometer where the balanced rotary mass is part of a current sensitive meter movement. The angular deflexion of the movement due to the applied acceleration is sensed by a capacitance pick-off which forms part of a r.f. oscillator circuit. The output is passed through a frequency discriminator and the signal is amplified to drive a current through the meter coil to oppose the motion due to the applied acceleration.

The feedback loop has damping and stabilizing characteristics. The coil current is a measure of the acceleration and can be made to produce 10 V/*g* across a fixed resistor when used as a linear accelerometer by out-of-balancing the coil system. The system is elegant although complex and has all the added advantages of negative feedback such as independence of loop gain and an adjustable frequency characteristic.

Measurement of vibration

A knowledge of the vibration levels present in the missile during flight is of the utmost importance to the equipment designer. He cannot always ensure that ground measurements during static firings are representative owing to the absence of aerodynamic loads and high accelerations. A considerable number of in-flight vibration measurements are therefore necessary in a weapons programme for proving components and laying down test specifications.

Preferably the vibration instrument should be able to measure dynamic accelerations up to several hundred *g*, containing frequency components from 10 c/s to 10 kc/s at various points in the structure. The dynamic

measurements must be made in the presence of steady manoeuvre accelerations of 20*g* or more encountered during the boost phase, and for this reason transducers using piezoelectric elements in compression or bending are employed. Vibration velocities are obtained if necessary by electrical integration of their output signal.

Natural piezoelectric crystals are not always suitable owing to their inability to withstand shocks and their hygroscopic properties. Although possessing a lower output —typically 20–50 mV/*g*—the artificial polycrystalline polarized ceramics such as barium titanate form useful transducers. The preloading mass compresses the ceramic under the influence of the inertial force, and the mechanical strain in the material produces a charge on the surface of the crystal. The acceleration is measured as a voltage developed across the crystal faces, which are flashed with silver to make electrical contact. The charge will of course leak away owing to the leakage resistance of the ceramic which acts as the dielectric and also because of the input impedance of the pre-circuit to which it is connected.

The transducer is therefore suitable only for dynamic measurements where the time-constant formed by the self-capacitance of the crystal, capacitance of the connecting cable, leakage resistance and input impedance of the amplifier, is long compared with the period of the vibration.

For some transducers measurements down to 20 c/s demand an input impedance to the amplifier of 100–200 MΩ. The transducer is extremely rugged for it can withstand an acceleration of several thousand *g* without damage and has reasonable cross-sensitivities, but there is an upper limit to the temperature at which it can operate. This occurs near the Curie point (120°C) of the

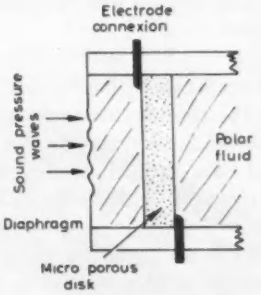


Fig. 5 How an electrokinetic transducer for measuring sound pressure operates

material and for this reason and because barium titanate gives a low sensitivity, other materials such as lead niobate, sodium cadmium niobate and lead zirconate are being tried (Fig. 4).

Measurement of sound pressure

Modern solid- and liquid-fuel rocket motors produce, as one would expect, abnormally high sound pressure levels. Thus energy is transmitted not only from the motor through the structure of the missile to sensitive components but also by high-energy acoustic waves.

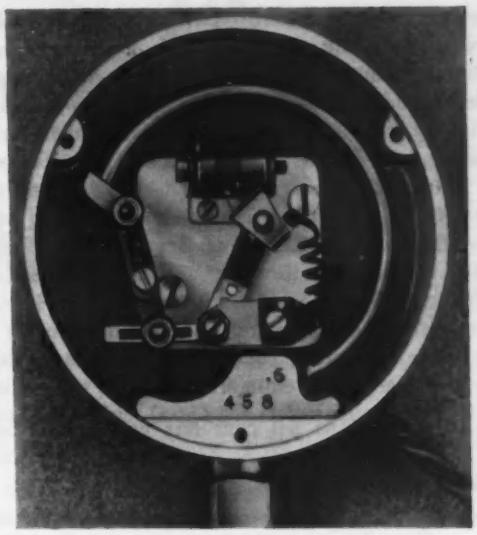


Fig. 6 A variable resistance pressure transducer

Measurement of the intensity of these waves over a large frequency and amplitude range has been difficult until recently. The application of a physical principle which uses the flow of a polar fluid through a microporous cell in a transducer has solved the problem.

The electrokinetic transducer (Fig. 5) consists of a diaphragm which forces the fluid through a porous ceramic disk and in doing so sets up a potential difference across the disk proportional to the applied pressure. The mechanical resistance to the flow gives the transducer an overdamped response, but the useful frequency range extends from 3 c/s–25 kc/s. Nominal sensitivities of 350 mV per lb/in² are achieved allowing pressure measurement over the range 70–210 dB (referred to 0·002 dyne/cm²).

The electrokinetic principle has also been applied to accelerometers.

Measurement of pressure

There are several different types of pressure transducer available which are arranged to measure absolute pressure or differential pressures of fluids and gases. High-level output devices use mechanical linkages for magnification of a diaphragm, siphon or Bourdon tube movement to move a potentiometer. Fig. 6 shows a typical pressure transducer. Mechanical linkages must not make the instrument vibration sensitive and therefore good designs have a mass-balanced movement. Other types of pressure transducer in general use for missiles have inductance pick-offs similar to the acceleration transducer (Fig. 3).

If it is necessary to telemeter corrosive fuel pressures, special diaphragms must be used or an inert diaphragm isolator with the intermediate volume filled under vacuum with a suitable oil. There are many other types of pressure measuring instruments using both bonded and unbonded strain gauges as detectors, but in general their low-level outputs are unsuitable for telemetry.

However for pressure measurements at extremely high ambient temperatures which may be encountered in recording pressure fluctuations in rocket motors, liquid-cooled bonded or unbonded strain gauges are necessary.

Fig. 7 shows the gauge element of a high temperature pressure pick-off which is capable of continuous operation at 600°F, and with a cooling jacket this limit may be extended to 2000°F. The platinum alloy wire which is wound between the posts has two active arms around the rhomboidal section strained in the direction of the arrow by the stainless steel diaphragm. The two inactive arms are wound on the posts mounted at the base of the transducer. These four arms form a Wheatstone bridge and their close proximity (the transducer is one half-inch in diameter) gives good temperature compensation.

Analogue or digital ?

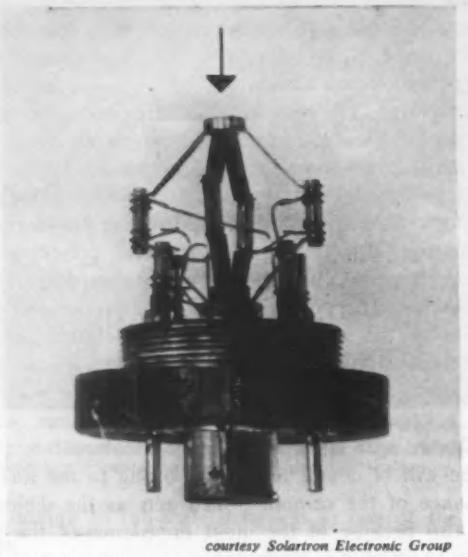
So far it has been assumed that all the telemetry transmissions will be in analogue form, i.e. a voltage level will be proportional to the physical quantity being measured. This signal can be mutilated by noise and fading below the threshold of the system. Digital transmission however is less susceptible to mutilation but high-speed analogue/digital converters are needed in the missile.

Clearly for the highest degree of accuracy the primary detector should be integral with the digital generator, and a system which approaches this ideal is the vibrating wire transducer. The principle of operation is shown in Fig. 8. The primary detector, which is the diaphragm of a pressure transducer, controls the tension of the wire and by evacuating the case the frequency of oscillation of the wire or 'string' will be determined by the absolute pressure on the diaphragm. The string is kept in oscillation by a transistorized feedback amplifier with an automatic level control.

The actual power required is a few microwatts since the string behaves as a resonant circuit with an extremely high Q. The string's natural frequency is a square-law function of pressure and the output may require linearizing, but since the mass of the system is extremely low the response of the transducing element is rapid and insensitive to acceleration forces.

Obviously this principle which is fundamentally that of a small displacement detector can be applied to many other types of transducer. For example a mass may be suspended by multiple strings and the beat frequencies between them will be a measure of the vector forces on the mass. Since the output signal is continuous in its frequency change with variation of these forces integration is readily accomplished by counting the oscillations, and its use in an inertial system may be visualized.

For guided missile research it has two obvious advantages. The output is a f.m. signal the centre frequency of which may be between 40 c/s and 70,000 c/s by choosing a suitable string and initial tension. This may be telemetered directly as the subcarrier without any other conversion. Secondly the principle of digitalizing in the transducer itself is more nearly approached since all that is required is a frequency counter rather than an analogue/digital converter to complete the digital system.



courtesy Solartron Electronic Group

Fig. 7 This unbonded strain gauge element operates as a high-temperature pressure transducer

Temperature measurement

The thermocouple is a low-level output device, and except for high temperature measurements and where a very fast response is needed a thermistor is used instead. The thermistor is a sintered mixture of various oxides and it has a large negative temperature coefficient of resistance.

It obeys the law

$$R = ae^{b/T}$$

where R is the resistance of the bead, a and b are constants and T is the absolute temperature. The constants a and b may be varied by proportioning the mixture of the oxides, and over the temperature range in which measurements must be made a large change of resistance can occur.

The thermistor is placed in one arm of a potential-divider circuit across a battery. At the junction of the two arms a high-level output voltage proportional to temperature is available. Care must be taken however to ensure that the self-heating effect is accounted for in calibration, or the current in the potential divider must be kept very low. The thermistors are manufactured in various forms to suit different applications. They can be sealed in glass for fluid and gases or bonded to a very thin copper disk for surface temperature measurements.

Flow measurement

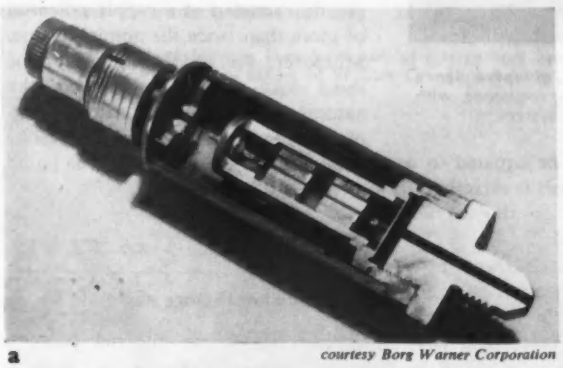
In liquid propellant rocket-motors the measurement of flow rates of the oxidant and fuel usually means inserting some form of transducer in the main feed pipes.

The transducer must not restrict the flow of the fuel, which rules out the orifice type of instrument, nor must there be any danger of pipe blockage if the instrument fails. Furthermore the transducer probably has to work in a highly corrosive fluid and its installation in the fuel system must not increase the possibility of leaks in high pressure lines.

One of the most reliable methods of measuring volume flow rate and total fuel used is to fit the inferential type of fuel meter. A suitably shaped vane containing a small magnet is suspended in bearings in the pipe. Fuel causes the vane to rotate at a speed proportional to the volume flow. Associated with the magnet and external to the pipe is a small pick-off coil into which is induced a pulse whose repetition frequency is determined by the number of revolutions per second of the vane. Thus the absence of direct coupling means that very little energy is extracted from the fuel flow, i.e. the pressure drop is small. Even if the vane jams in the bearings the drop is probably insignificant.

Fig. 9 shows a typical flowmeter in section which has been designed so that the venturi effect eliminates the need for a thrust bearing and the transducer has virtually a floating rotor.

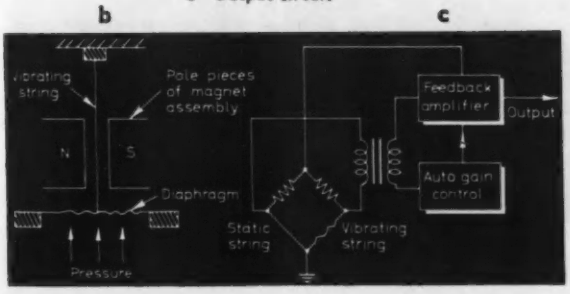
When hydraulically centred the rotor spins freely and this ensures good linearity and range of operation. Owing to the free rotor certain flowmeters of this type are capable of measuring extremely short transients in flow of less than 0·01 s. The main problem in flow measurement is the transmission of the pulse train from the pick-up to the ground station via telemetry. This requires one high frequency channel if the pulses are to be counted on the ground to evaluate the total fuel flow. For less accurate measurements it is sufficient to derive a signal proportional to flow rate in the missile



a *courtesy Borg Warner Corporation*

Fig. 8 Vibroton digital pressure transducer
a Cut-away view
b Principle of operation
c Output circuit

b c



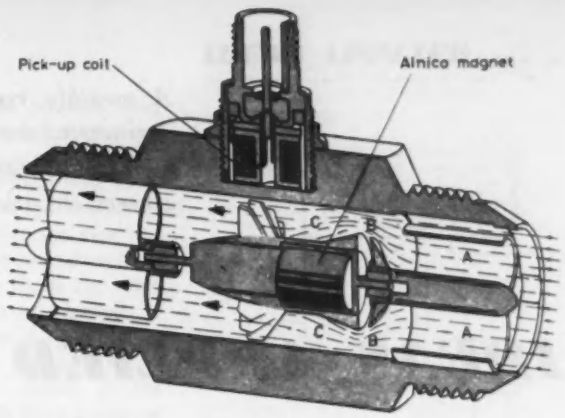


Fig. 9 The free rotor of an electronic flow sensing element permits an excellent transient response

before telemetering and then the channel bandwidth can be much narrower.

A disadvantage of this transducer is that it is essentially a *volume* flow indicator and the propulsion engineer is often more interested in *mass* flow. There are one or two instruments which measure mass flow directly or apply corrections automatically to volume flow instruments, but these are not particularly suitable for missile applications.

It is easier to measure the density of the fuel and to make in-flight measurements of the tank temperature so that corrections to apparent mass flow may be made.

Measurement of attitude and angular velocity

Gyroscopes have not been developed specifically for research and test purposes since they generally form part of the autopilot or guidance system, and are present in the missile in any case. However the data that they produce throughout flight in the course of controlling the missile are nevertheless required during test programmes. The measurement of attitude with respect to some predetermined space datum is accomplished with a *free* gyro. This is the familiar instrument comprising a high-inertia rotor supported by three orthogonal gimbals, the outer one being fixed to the missile airframe. Suitable electrical pick-offs measure the relative angular movements between gimbals as the missile manoeuvres; these are used as control feedbacks, and can be recorded for test purposes.

The measurement of angular rates is most often obtained from a *rate* gyro. In principle this instrument is similar to the free gyro except that the rotor or inner gimbal is constrained by a spring. The device uses the well-known phenomena of precession, where if a rotating mass has a torque applied to it perpendicular to its axis of spin, i.e. because the missile is rotating, the spin axis is rotated, i.e. precesses, in a direction mutually perpendicular to the spin axis and the axis of the applied torque. The precession torque is measured as the deflexion of the spring using a suitable pick-off. Some damping is provided by a mechanical dashpot.

Such motions in trials programmes are also measured externally by the use of kine-theodolites and other optical methods, and by radio methods.

A monthly review—under basic headings—of the latest control engineering developments for all industries; specially edited for busy technical management, plant and production engineers, chemical engineers, etc., who are not specialized in instrument and control systems

IDEAS APPLIED . . .

. . . to SPEED

An improved governing system for small electric motors

R. C. WESTON, Signals Research and Development Establishment

In the conventional governor a contact is caused to open or to close as the governing speed is reached. This contact action causes the motor to decelerate until the governor contacts have returned to their original state. The speed control achieved in this way is subject to hunting since there is no gradation in contact action between the two states of fully open and fully closed. Moreover no improvement is achieved by adding inertia to the motor, since this results in the same excursion of speed at a lower frequency of hunting.

The improved governor system enables the governor contacts to be used as a 'variable resistance' which is continuously variable between the limits of zero and infinity. A movement of the centrifugal system with variation in motor speed, within the governor range, is used to provide a controlled adjustment to the 'governor resistance' to produce an immediate readjustment of motor speed. The result is a close control of motor speed without any hunting.

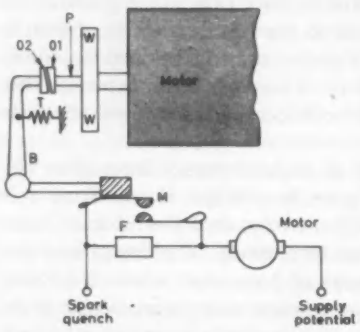


Fig. 1 A typical arrangement of the improved governor system applied to a series-controlled a.c. machine

A vibratory motion is introduced into the contact action, additional to the normal make/break action resulting from the centrifugal system. The vibratory amplitude matches the normal movement of the governor contacts over the desired governing speed range.

This vibratory motion—conveniently produced by the motor shaft rotation—causes an agitation of the governor contacts such that the repeated opening and closing may be equated to a make/break ratio which is directly related to the average position of the governor contacts.

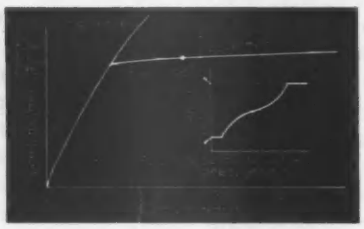


Fig. 2 The variation of speed for a 230 V 60 W a.c. motor equipped with the improved system

Fig. 1 gives a typical arrangement for a series controlled a.c. motor but it is equally applicable to d.c. machines. A system of centrifugal governor weights W causes a pin P to emerge as governing speed is reached. This pin bears upon the bellcrank B tending to lift the moving contact M away from the fixed contact F.

Vibratory motion is introduced by the two oblique surfaces 01 and 02. Surface 01 is attached to the governor pin P and thus rotates at motor speed. Surface 02, being attached to the bellcrank system, does not rotate. The surfaces are held in rubbing contact by a tension spring T. During each complete rotation of the motor shaft, the rubbing action of the oblique surfaces causes the bellcrank to execute one cycle of vibratory motion.

A small increase in motor speed causes a further emergence of pin P and an immediate change in the duty cycle of the governor contacts, in that they are opened for a greater proportion of each cycle. In similar manner a small reduction in motor speed is accompanied by a retraction of the governor pin, and an immediate and opposite change in the duty cycle of the governor contacts such that they are closed for a greater proportion of each cycle.

The variation of speed for a 230 V 60 W a.c. motor equipped with the device is shown in Fig 2. It will be noticed that nominal speed is not greatly exceeded at a supply potential of more than twice the nominal value. Moreover, the sudden imposition of shock load, within the limit of the natural (i.e. ungoverned) characteristic of the motor does not produce variations in motor speed outside the limits of nominal governing range.

. . . to FLOW

A constant resistance valve

In factories where material is conveyed pneumatically it is usually necessary to provide a separate compressor for each pipeline. The reason for this is that if several lines are blown from a single compressor, then the air tends to take the path of least resistance, and a heavily loaded line will be bypassed, which may lead to a blockage. To prevent such bypassing individual compressors are fitted to each blowing line. This has a num-

ber of disadvantages including multiplication of plant, and higher installation and maintenance costs.

The Simon sonic valve has been designed to overcome this problem by providing a fixed resistance in each of the blowing lines. In this way one compressor can supply equally a number of lines, irrespective of the load being conveyed in each line.

The fixed resistance is provided by a choked nozzle, which has the property that the mass flow through it remains independent of the downstream pressure. The principle has long been familiar to designers of gas turbines, and Henry Simon have applied it to their sonic valve. The mass flow

Fig. 3 Flaws at the throat of the nozzle can cause shock waves which lead to large pressure losses, and they are well shown in this shadow photograph

through the valve will stay constant no matter how small the load on its outlet may become. This will prevent the bypassing of heavily loaded lines.

The pressure drop across the valve is sensitive to imperfections in the surface at the throat of the nozzle. The photograph (Fig. 3) shows the shock waves produced by a badly finished throat and by surface flaws in the divergent section. The pressure drop can be reduced by careful machining, but the loss of efficiency is compensated by the use of fixed flow compressors which would be unsuitable for blowing lines where the flow was irregular. The later sonic valves have a variable throat by which the value of the mass flow can be adjusted.

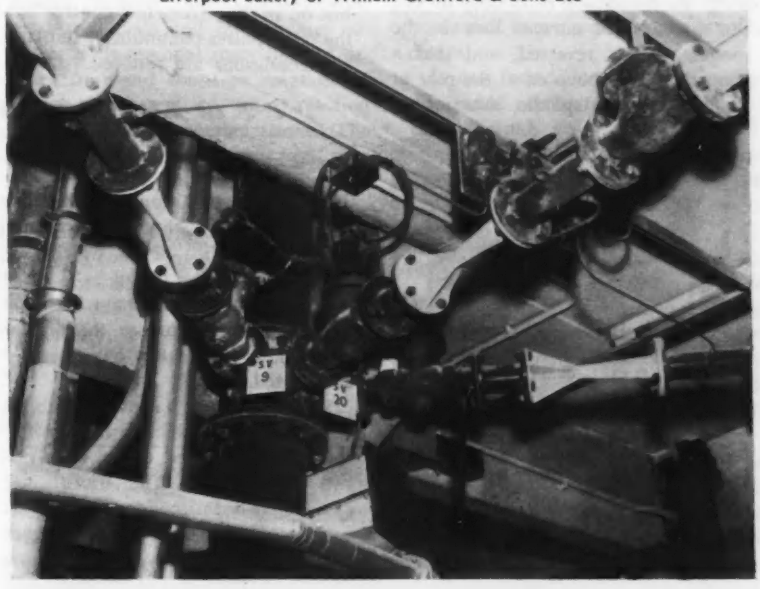
The valves shown in the photograph (Fig. 4) form part of a bulk handling system installed by Simon at the Liverpool bakery of William Crawford & Sons Ltd. There are 12 blowing lines powered from one compressor through an air receiver, the main compressor being aided, when necessary, by a smaller boost compressor. The pressure tappings on the section downstream of the sonic valve are fed to pressure switches (just visible in the photograph) which bring the boost compressor into operation when the pressure falls too low. The material to be conveyed is delivered into the blowing line by a rotary valve, which is fed from a hopper. The rotary valve is in a section after the sonic valve. The solenoid valves which precede the nozzle are used to cut the flow to any particular blowing line.

. . . to CURRENT DENSITY

Increased efficiency in cleaning and pickling operations

In continuous strip processing it is sometimes necessary to pass strips of

Fig. 4 These three blowing lines form part of a large bulk handling system at the Liverpool bakery of William Crawford & Sons Ltd



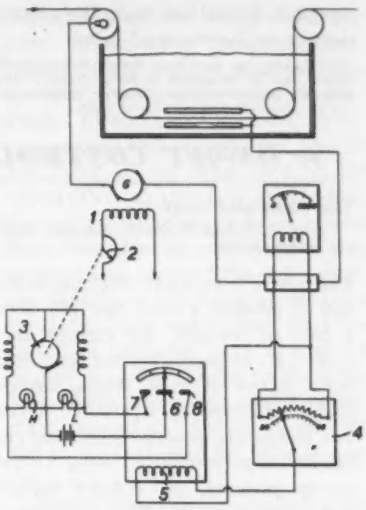


Fig. 5 A method of controlling the current density in continuous strip processing

different widths through an electrolyte, a current being fed from the strip to an electrode immersed in the electrolyte. For cleaning and pickling operations the current density must be maintained near certain limits, while the speed is of minor importance. If the current density is too low the cleaning and pickling of the strip will not be complete, no matter how slowly the strip passes through the electrolyte. On the other hand if the current density is too high then the strip may be damaged and an excessive amount of current will be used.

A patent for a simple, cheap method of regulating the current density has been published recently (British Patent 809,341 to the United States Steel Corp). The layout of the method can be seen from Fig. 5. The current from the generator G is passed through a shunt and across the gap between the strip and the electrodes in the electrolyte. The current in the field coil (1) of the generator can be altered by a variable resistor (2) driven from a split-series servomotor (3). The width of the strip is set up on the potentiometers (4); this is a measure of the current density required. It is compared with the voltage derived from the shunt and the difference fed to an ammeter coil (5). If the current density falls outside its limits the ammeter needle, together with its contact (6), will move across the dial and touch one of the two adjustable contacts (7, 8). The servomotor will rotate and drive the variable resistor in the

direction which will bring the current density to the required value.

This abstract was made from British Patent Specifications with the permission of the Controller of Her Majesty's Stationery Office. Complete specifications can be obtained from the Patent Office.

to ON-OFF CONTROL

The calibrated relay

J. M. KINGSLAND, Smiths Industrial Instrument Division

There have been many attempts in the past to produce a relay that will close a pair of contacts, for control purposes, at a predetermined electrical input. Many of these relays, though giving precision in operation, often lack robustness in construction and reliability in performance, owing to low contact pressure, and contact bounce under conditions of shock and vibration.

The patented calibrated relay, which has successfully overcome these shortcomings, takes two basic forms, generally called the *up-sensing* and *down-sensing* relay.

The up-sensing relay

The up-sensing relay, so termed because its contacts close on rising current, consists of a moving coil operating in the air-gap of a loudspeaker-type permanent magnet iron circuit. This magnetic circuit produces a high air-gap flux density and combines with the multi-turn moving coil winding, the whole of which is contained in the air-gap, to produce an efficient electromagnetic system. The moving coil is supported on a stainless steel spindle in two sapphire jewel bearings. It carries a contact and a soft iron armature bar which is magnetically locked, owing to leakage flux from the magnet, to two auxiliary pole pieces secured to the top plate of the relay.

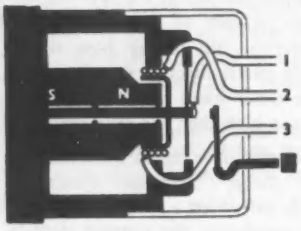


Fig. 6 The up-sensing relay closes its contacts on a rising current

The operation of the relay is shown in Fig. 6. The moving coil is de-energized and the moving coil spindle is held in against a back stop by the magnetic force acting on the armature bar. As the direct current through the coil rises, an electromagnetic force is built up to oppose the armature locking force and the coil moves slowly out until the armature bar tips the auxiliary poles. Thus the locking force on the armature bar rises to a maximum at the auxiliary pole tips, and then falls off, approximately to a square law, as the setting current is exceeded, and the armature bar breaks from the poles, rapidly closing the contacts and making the circuit through 1 to the shaded lead.

The greater part of the electromagnetic force developed in the moving coil is utilized for contact pressure, but a small restraining force remains which will automatically reset the relay when the current falls to approximately 50% of the setting current.

The permanent magnet is aged to ensure stability, and the relay setting current is ranged during manufacture by adjustment of the auxiliary poles. The standard relay has a 600-turn moving coil wound in aluminium wire with a setting current in the range 10 to 14 mA d.c. The silver contacts are rated at 1 A, 250 V a.c., and the minimum contract pressure on closure is 15 g. Other coil windings can be used to give setting currents within the range of 1 mA to $\frac{1}{4}$ A, but as with the conventional moving coil meter higher currents may be handled with the aid of shunts, or instrument transformers.

The down-sensing relay

This operates to close a pair of contacts when the current falls to a precise value, and differs in construction from the up-sensing relay only in that the direction of current flow in the moving coil is reversed, and that a control spring, mounted at the rear of the moving coil spindle, acts in opposition to the magnetic locking force on the armature bar and the electromagnetic force developed in the coil.

Fig. 7 The down-sensing relay is on the left, and it is shown here applied to ventilating fan failure equipment

Applications

It will be appreciated from the above that a positive action and precision of setting, to within ±1% under static conditions, is only obtained with closure of the relay contacts. Whilst both relays automatically reset, and in some cases this can be used for control purposes, the accuracy of reset is reduced to ±5%. Many applications, though, require high accuracy in one direction only, and a typical example of the use of up-sensing relays has been to a combined diesel engine starter isolation and overspeed protection unit. Both up-sensing relays are identical, and interchangeable, though their settings are 300 and 1600 rev/min respectively. An instance of the use of a down-sensing relay, without reset coils has been to ventilating fan failure equipment (Fig. 7).

In some applications it is desirable to have a very close differential between the setting and resetting points of a relay. This may be accomplished by a pulsing technique so that immediately the calibrated relay triggers it is made to reset by using secondary relays. After a short time delay the calibrated relay is allowed to retrigger if the current remains out of limits.

The combination of both an up-sensing and a down-sensing relay in a circuit can be used to give a controlled differential between two settings, and when also combined with the pulsing technique it can be used to control a voltage or current, via a servomotor, to within ±1%. So long as the quantity remains within the control band neither calibrated relay is in operation, but on passing from this control band the relay pulses continuously until normal conditions are restored.

. . . to EDUCATION

A synchro teaching rig

The College of Aeronautics have devised a novel method of connecting standard synchro units which they have found to be useful as a visual aid. Once the synchros have been connected it is easy to see the type of circuit into which they have been incorporated.

Photograph Fig. 8 shows the fabricated alloy frame which is fitted with a switched and fused mains supply to two transformers. The transformers provide two independent 50 V r.m.s. supplies at 50 c/s for synchro energization. Each supply is brought out

to four pairs of 3 mm sockets, on one side of the frame.

The front of the frame holds six interchangeable mounting plates, secured by quick fasteners. These plates are designed to receive standard 3 in. Admiralty Pattern synchros, which are held in place by a locking plate and 2 BA studding. The various stator and rotor windings are brought out to six 3 mm sockets arranged in two groups of three, thus separating the stator and rotor connexions. An iden-

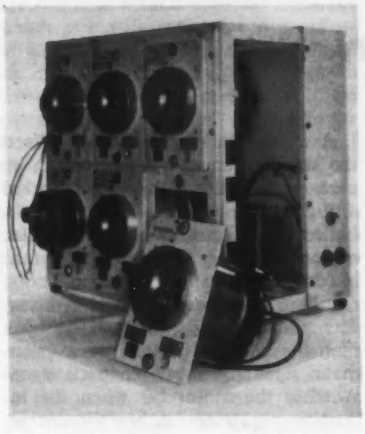


Fig. 8 The synchro rig has proved to be of great use as a visual aid

tifying label is fitted to each plate, and interconnexions are made with short leads terminating in 3 mm plugs.

Each frame is normally fitted with 2 control transmitters, 1 control transformer, 1 control differential transmitter, 1 resolver (No. 1) and 1 torque differential receiver. All except the torque receiver are supplied with graduated dials and index plates together with optional rotor locking devices to avoid the free rotation of rotors which results from reaction effects in some configurations. The torque receiver has a radius arm upon which may be hung a weight carrier for the measurement of torque.

To allow experiments involving synchros as computing elements, an ancillary unit has been provided carrying two inductive potentiometers with graduated scales and 3 mm socket terminations.

. . . to LEVEL

Steel cylinder instrumentation

Here is an instrumentation problem that has been submitted to us and which readers might like to tackle. It is concerned with finding the level of liquid carbon dioxide in steel cylinders. The cylinders have various capacities up to 100 lb, and at normal temperatures (60°F) the pressure within the cylinders remains virtually constant, while any liquid is present, at approximately 750 lb/in.^{2}.

It is impracticable to fit any equipment inside the sealed cylinder, and the level indicator, together with its detector, must be entirely external to the steel cylinder. Apparently weighing the cylinders is not a satisfactory method.

If anyone has an answer to this problem then we should be pleased to hear from him.

. . . to INSTRUMENT DESIGN

A new approach to magnets

J. THILLAIMUTHU

The unique flux leakage-free property of the toroid is well known in electromagnetism though not fully explainable in terms of classical physics, and is still an enigma. Attempts to use the toroidal form in permanent magnet circuits, providing the airgap necessary for useful applications—invariably a radial slot—have not produced the desired results because the symmetry of the system is broken, giving rise to fringing and leakage fluxes.

In the course of developing an electromagnetic computing element which called for unusual and stringent requirements in the design of the magnetic circuit, a basic discovery was made that may revolutionize magnetic design.

It was found that if a ring magnet was made in the form of either half of a toroid, split circumferentially along the mean diameter and if a core or yoke of complementary form was nested in the former, the unit exhibited the leakage free property of a toroid for *all directions of magnetization of the magnet component*, provided the core was not saturated. Such a construction allows for a symmetrical airgap along the mean diameter and covers directions of magnetization other than the usual circumferential magnetization.

Probing further the function of shape based on the split toroid forms, it was found that a ring magnet made in the form of the external half of the split toroid (EST), and axially magnetized, exhibits largely a freedom from the so-called cylindrical component of the field, if used to focus an axially symmetrical beam of electrons. It was also found that if the ring is used with a soft iron core of the shape of the inner half of the toroid (IST) so that it is axially free, the mutual attraction is much greater than that due to conventional ring magnets and cores of the same external dimensions and material, although the latter have more mass; and the cut-off in attractive force as one was pushed or pulled relative to the other was greater. Solenoids, cored or uncored, wound to the shape of the split toroid (EST) showed the same properties.

These observations indicate that magnetic force can be largely, if not completely, controlled by designing

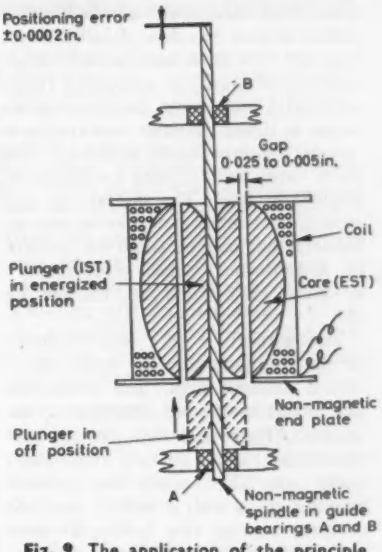


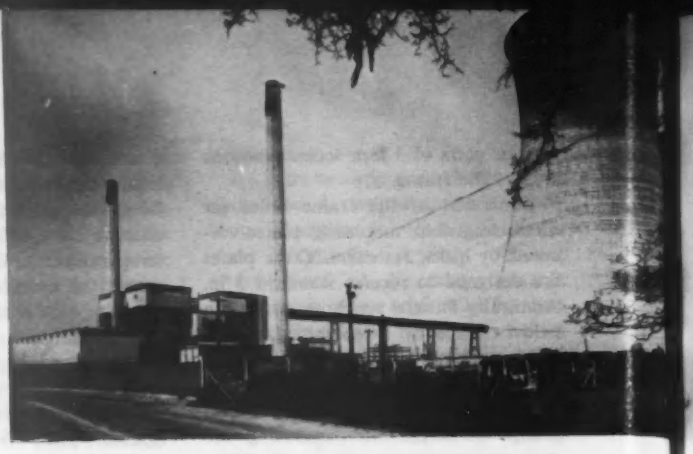
Fig. 9 The application of the principle to a solenoid

magnetic circuits around the split toroid forms, and the symmetry that it offers.

Many varied applications will suggest themselves, where freedom from leakage flux, screening effects are desired or higher efficiency/weight ratios are required. The following are some examples taken at random:

1. Electric motors and generators—increased efficiency and self-screening effects, lower weight.
2. Tachogenerators (a.c. and d.c.)—improved linearity, self-screening effects, lower weight.
3. Meter movements, moving coils, etc (see Fig 1)—improved linearity, torque and self-screening effects.

To be concluded



CONTROL IN ACTION

Pneumatic system with three-element feedwater control

Boiler Control at Willington 'A'

IN THE VILLAGE OF WILLINGTON, NEAR Burton upon Trent in Derbyshire, the 'A' half of a new 800 MW thermal power station is nearing completion. This first half of Willington power station has four English Electric 100 MW hydrogen-cooled turbo-generators, with four associated International Combustion boilers, operating at a steam pressure and temperature at the superheater outlet of 1600 lb/in.^{2} and 1060°F, with a capacity of 830,000 lb/hour. The boilers are pulverized-coal fired, each having sixteen burners that can be tilted for control of superheated steam temperature; automatic oil firing is used for lighting up.

The station is of 'semi-outdoor' design, implying that the boiler flues, forced draught fans, dust extractors and precipitators are exposed to the weather. There are two parallel turbine halls, each with two turbo-alternator sets. The boilers are grouped between them with a 425 ft concrete chimney serving two boilers at each end of the building. Between the turbine halls and boilers, and looking onto them, lie the two plant control rooms.

New feedwater control

Automatic boiler control is effected pneumatically with hydraulic and electric actuation of valves and motors. Designed by the main instrumentation contractors, Electroflo, in conjunction with the CEGB and the consulting engineers for the station plant, Ewbank and Partners, it contains many instruments and regulators similar to those used in other power stations. But the system has the new Electroflo three-element feedwater control, and moreover it is very highly centralized. The boilers are fully regulated from the plant control rooms, thereby dispensing with control panels near each boiler.

Boiler steam pressure

The two main quantities in the steam-raising process which are automactically regulated are main steam pressure, and water level in the boiler drum.

A change in steam pressure affects the coal feeder and exhauster fan on each fuel mill and also the forced draught fans on the air inlets to the boiler. Each of the a.c. commutator motors working the feeder and fans is controlled in speed by an induction regulator positioned by a pilot motor. The pilot motor is switched on by a mercury switch actuated by a pneumatic signal. A local feedback signal switches the motor off when the induction regulator reaches the correct position. Changes in steam and air flows, corresponding to changes in electrical load or combustion conditions, also affect the speed of the forced draught fans. The control is combined so that a fall in steam pressure causes an increase in fuel-flow/air-flow ratio, while an increase in steam flow causes an increase in fuel flow and air flow.

The fourth main regulating element in the boiler control system is the variable-speed induced draught fans on the outlet flue of each boiler. These are controlled by the combustion

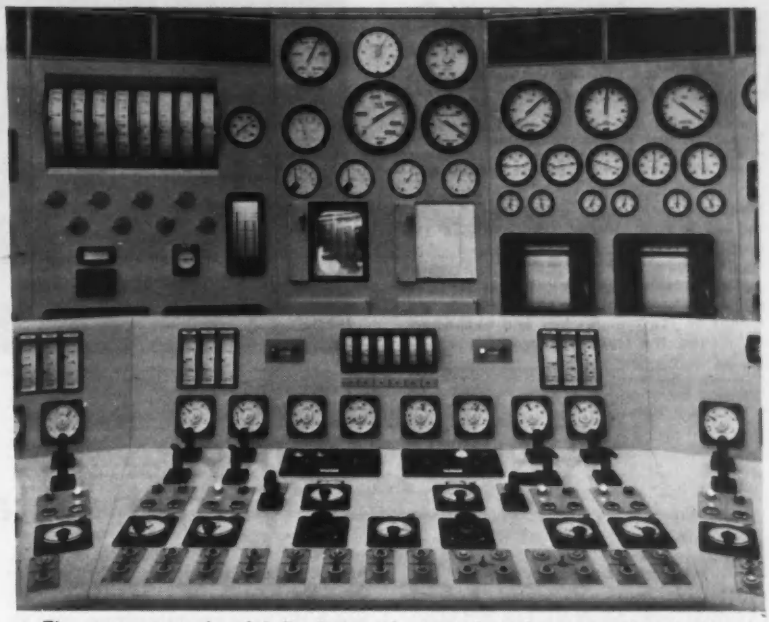
One of the two plant control rooms at Willington 'A' station, with the shift engineer (white overalls) and his two technician assistants (blue overalls). Each control room handles two 100 MW boiler/turboalternator units, and in the right rear can be seen the instrument panels for one boiler and turbine. These consist of an inner low angled control console, miniature indicating instruments and outer panels with full-size indicating and recording instruments; all manual controls are on the inner console. In the centre rear is a control desk for the oil-firing equipment with a large glass window behind it looking onto the turbine hall. To the left is the inner control console for the other unit

chamber suction, working in a separate control loop. Normal working suction is around 0·2 in. w.g.

Drum level (feedwater control)

The feedwater control—designed to maintain the boiler drum water level—is of the three-element type—boiler drum water level, feedwater flow, and total steam flow being the measured parameters. Most existing power stations have only a two-element system, feedwater flow not being directly taken into account. Pneumatic signals corresponding to the three parameters are fed into a three-element regulator which primarily ratios feedwater flow to steam flow, this ratio being biased as necessary on the basis of drum level deviations. The pressure of these signals—about 1–12 in. Hg—is lower than standard owing to the nature of the square root extracting type of differential pressure cell employed on steam and flow measurement. The system uses hydraulically actuated feedwater regulating valves to provide the necessary thrust (about 2000 lb) in the large-bore feed main. A temperature equalizing column is used to detect water level in the boiler drum; this has water in one side and steam in the other, with a small weir at the top. Changes in level cause a change in transmitted differential pressure, the correct level being represented by a pressure of 9 in. w.g. The feed main, three-element regulator and hydraulically operated valve are duplicated.

Besides the control of main steam pressure and feedwater flow, Willington has several other examples of autocontrol equipment. Perhaps one of the most impressive is the Neckar feedwater treatment plant to control alkalinity of make-up water passed to the evaporators. The pumps supplying caustic soda and sulphuric acid are switched on and off automatically by



The master control and indicating panels situated at the centre of each side of the plant control room. Manual controls of feedwater pumps, dampers, induced draught fans, etc., are on the console in front, and the central panel behind carries instruments giving steam pressure, steam temperature, feed flow, combustion chamber suction and load (megawatts). Two Marconi closed-circuit television systems will be fitted; the screen shown displays water level indicators on the boiler drum; the second screen will allow flame observation (the vacant space to the right of the level display is for this). Some 140 visual alarm indicators are fitted along the top of the indicating panels, a few of which can be seen here: the more urgent, e.g. 'Drum level low,' light up in red, the others in yellow

Honeywell controllers, pH measurement being by Electronic Instruments meters. The plant is unmanned though an operator inspects it at intervals.

Labour saving

Willington does not represent the latest thought in instrumentation and control of a thermal power station—for example no automatic data-logging is fitted. Much of the instrument planning was indeed done in 1954. As noted above, the salient feature is the centralization of control, and this includes operation of all important auxiliaries such as boiler feed pumps from the plant control room. Moreover this central control achieves an unusual saving of labour—the total operating staff for each shift in a control room and turbine hall is only five, compared with about ten in many older equivalent stations.

In addition to Electroflo, other manufacturers that have supplied instruments for the boiler control include Cambridge Instrument, Evershed & Vignoles, Kent, and Sunvic Controls.

A sign of the times is that Willington 'B' Station, comprising two single

Another view of the plant control room shown on the left. The full extent of the angled control console can be clearly seen. Four of the panels on this handle the four p.f. mills associated with each boiler while the one on the extreme left is the superheater control panel. The engineer stands at the control desk for the two generators, and the graphic panel behind is for the station transformers. (Note that the only other graphic panel used in the control room is that for the cooling water plant, not visible in these illustrations)

200 MW units, is to use an electronic system of automatic boiler control. The first unit will probably be commissioned in 1962.

Acknowledgment is made to the East Midlands Division, Central Electricity Generating Board, for premission to publish this article, and to the Staff of the Willington Station, for help in preparing it.

Electroflo pneumatic transmitters mounted on a floor of the station above the level of the plant control room. The master steam unit accepts the full working pressure and transmits a low-pressure signal to the control system regulating the speeds of the mill feeders and exhausters and the forced draught fan

Counting control in zip fastener manufacture

THE MANUFACTURING PROCESS BY which Lightning Fasteners Ltd of Glasnant, near Swansea, (an ICI company) produce their new 'Nyzip' zip fastener, is said to have been greatly

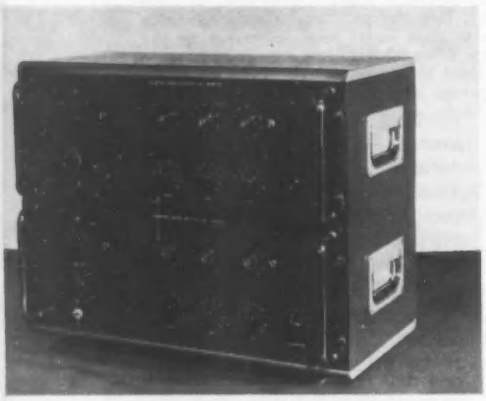


Fig. 1 An ETL counting control unit of this type is now speeding 'Nyzip' zip fastener manufacture at the Glasnant works of Lightning Fasteners

speeded up by the introduction of Ericsson Telephones' counting control equipment. Lightning Fasteners required a control instrument which could be attached to their existing production machinery, in order to enable the individual members of the fasteners to be affixed in equal numbers to the inner edges of the zip fastener tapes. Furthermore, they wanted the instrument to brake the machine whilst allowing the tape to run on freely at the end of each predetermined length of zip fastener.

Control by electronic counter

The problem has been overcome with an ETL counting control unit, type 163A. This counts each minute member and, when the predetermined number has been reached, brakes the machine, counts the spaces through which the tape must be run on, restarts the machine at the end of each pause and simultaneously operates a knife solenoid to cut the length of tape into individual fasteners. It also counts the number of zip fasteners produced.

The type 163A, which is illustrated in Fig. 1—not, unfortunately, on the Nyzip machine—consists of two modified ETL batch counters, type 102C, which are arranged to count from a single pulse source, contained in compact casing to make a single installation. The diagram of Fig. 2 shows that, in effect, there are two predetermining counters operating in double-channel recycling fashion.

High-speed operation

A contact breaker driven by the 'Nyzip' machinery provides a positive d.c. signal for each member or space unit to be counted. This signal is fed into the 'spaces' counter. When the desired count has been reached, the spaces counter is automatically reset and the input signal is switched into the 'members' counter. The signals are counted into the members counter until the selected number has been recorded. This counter then resets and the signals are re-routed back into the spaces counter. This cycle of operation is repeated whenever signals from the contact breaker are present.

At the conclusion of each members' count, a mechanical register is impulsed to record the number of zip fasteners produced.

The numbers of members and spaces required on the 'Nyzip' are set up by switches on the front panel of the counting control unit.

According to Ericsson Telephones, the installation of these instruments enables absolute accuracy to be maintained and has now so speeded the manufacturing process that the tape can be run through at a rate slightly higher than 2500 members and spaces per minute. Ericsson's Instrument Division have produced a comprehensive range of electronic counters over the past three years and claim to be able to cater for almost every counting, timing and batching problem presented by industry today.

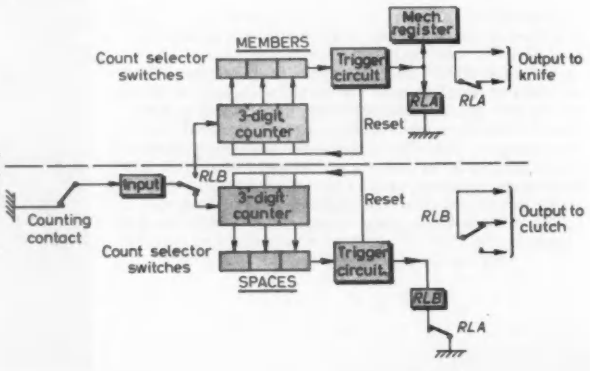


Fig. 2 Schematic diagram of the counting control equipment

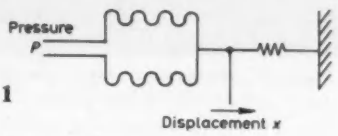
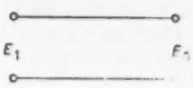
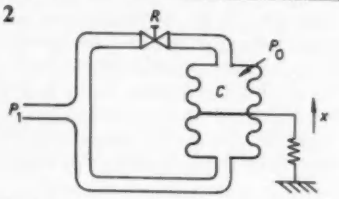
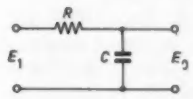
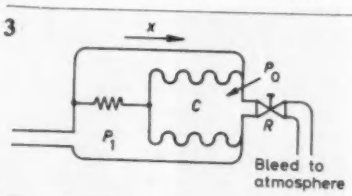
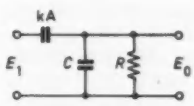
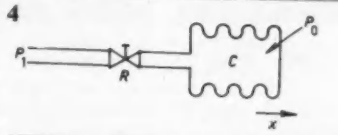
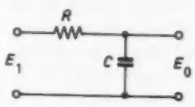
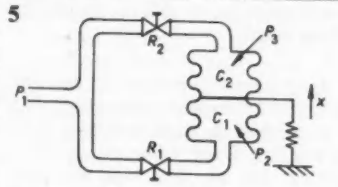
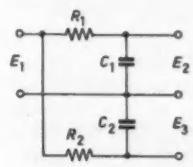
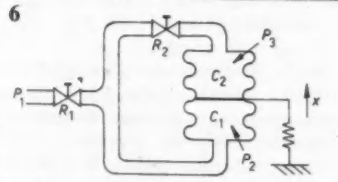
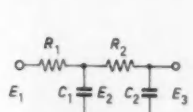
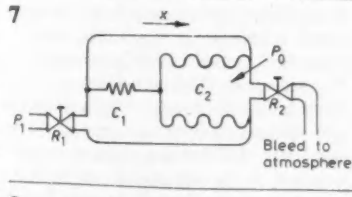
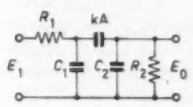
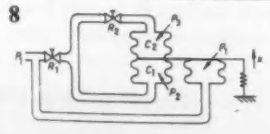
DATA SHEET-11

Pneumatic feedback circuits

by **NOEL REAM**
Reader in Control Engineering
Battersea College of Technology

THE TABLE LISTS THE TRANSFER functions $Y(p)$ which are generated in the *feedback* paths of some typical pneumatic controllers. P_1 is the output pressure generated by the controller through its flapper/nozzle amplifier and output air relay; and x is the output of the feedback circuit. The remarks concerning controller actions are based on the assumptions that the amplifier gain is large (no appreciable flapper movement) and the pneumatic lags in the amplifier and relay are small. Then the *overall* transfer function (P_1/error signal) is approximately $1/Y(p)$.

In practice pneumatic resistances are far from linear, particularly near zero flow, and all elements are affected by pressure and temperature changes. Thus the linear transfer functions are only a guide to the actual response. Since only passive networks are shown ,all the 3-term circuits give interaction.

	Pneumatic Circuit	Equivalent Electrical Network	Transfer Function $Y(p)$	Remarks
1			$\frac{x}{P} = k$	Used as proportional feedback converting pressure to displacement. Gives proportional action. k refers to combined resilience of bellows and spring.
2			$\frac{x}{P_1} = k\frac{P_1 - P_0}{P_1} = \frac{kpCR}{1+pCR}$	Gives proportional-plus-integral action. C refers to whole volume occupied by air at P_0. Closing restrictor ($R = \infty$) gives proportional action but proportional factor then depends on 'trapped' P_0.
3			$\frac{P_0}{P_1} = \frac{kA}{\left(kA + C + \frac{1}{pR}\right)}$	Gives proportional-plus-integral action. k = spring movement/unit pressure change. A = area of bellows. See (2) for remarks concerning proportional action.
4			$\frac{P_0}{P_1} = \frac{1}{1+pCR}$	Gives proportional-plus-derivative action; proportional alone when $R = 0$ (restrictor wide open).
5			$\frac{x}{P_1} = k\frac{P_2 - P_3}{P_1} = \frac{kp(C_2R_2 - C_1R_1)}{(1+pC_1R_1)(1+pC_2R_2)}$	Gives 3-term action. Requires $C_2R_2 > C_1R_1$ to avoid positive feedback in controller. No integral action if 'integral' restriction R_2 closed; no derivative if 'derivative' R_1 wide open. 'Parallel' or 'symmetrical' 3-term circuit.
6			$\frac{x}{P_1} = k\frac{P_2 - P_3}{P_1} = \frac{kpC_2R_2}{(1+pC_1R_1)(1+pC_2R_2)+pC_2R_1}$	'Series' or 'unsymmetrical' 3-term circuit. Differs from (5) in the ratio of proportional, integral and derivative terms generated with given resistances and capacitances.
7			$\frac{P_0}{P_1} = \frac{1}{[(1+pC_1R_1)(1+\frac{C_2}{kA}+\frac{1}{pkAR_2})+\frac{R_1}{R_2}(1+pC_2R_2)]}$	Addition of 'derivative' restrictor to (3) gives 3-term action. Terms differ from (5) and (6).
8		as (6)	$\frac{x}{P_1} = k_2\frac{P_2 - P_3}{P_1} + k_2$ where $\frac{P_2 - P_3}{P_1}$ is given in (6)	Shows provision of additional bellows transmitting a proportional term to x directly. This prevents $Y(p)$ becoming very small as $p \to \infty$ and stabilizes the controller at high frequencies.

PEOPLE IN CONTROL

by Staffman

MacLELLAN, BISHOP, JONES, BALL, GRENSTED
Control and the Mechanicals

My heading illustration was taken at the recent Cambridge Conference on automatic control which is reported in News Roundup on page 109. The object of the Conference, which was a joint effort of the Mechanicals and the University's Department of Engineering was to discuss the influence which control engineering should have on the education of mechanical engineers. The photograph shows, left to right, Dr **G. D. S. MacLellan** of Cambridge, Professor **R. E. D. Bishop** of University College, London, Air Marshal Sir **Owen Jones,** who was at the time President of the Institution of Mechanical Engineers, Mr **E. Bruce Ball,** Member of the Council and of the Education Committee of the Institution, and Dr **P. E. W. Grensted** of Cambridge. Incidentally the new President of the Mechanicals is **H. Desmond Carter,** of the Diesel firm Crossley Bros, Openshaw, Manchester.

D. A. Senior, a Senior Principal Scientific Officer of DSIR, has been appointed Scientific Attaché to the British Embassy in Moscow, and I cannot help wondering how his job will compare with that of **Thomas H. Osgood** who, as I reported in March, holds a similar position in London with the American Embassy. Now on a preliminary visit to Moscow,

SAMSON
Food for thought

SENIOR
Snow on his boots

Senior's duties will be to 'advise the British Ambassador, Sir **Patrick Reilly,** on scientific matters and report on Soviet scientific and technical matters in the civil field.' An ex-RNSS man, he was at the Admiralty Research Laboratory investigating problems of instrumentation and combustion.

I was surprised to hear that **J. E. Samson** had left Foxboro-Yoxall to join his father's company, Samor Pure Foods. He told me over lunch that 'the instrument industry pays insufficient attention to the newer techniques. At the moment the instrument manufacturer tells industry what it needs, but this situation may well be reversed.' Furthermore 'system design is practically non-existent.' Samson is an authority on control engineering—you may remember his article on pneumatic systems which appeared in our first issue. I hear he is to receive the SIT's Bowen prize for his paper 'Dynamic Characteristics of Pneumatic Transmission.'

Last month I reported **Laurence Malec's** appointment as MD of Solartron Radar Simulators and said that prior to this he was MD of Air Trainers Link. **A. W. Whitehead,** Air Trainers' joint Secretary, has given me a gentle rap over the knuckles, pointing out that Malec was not MD but Head of Sales and a Director. Whitehead tells me that **Norman Hall** has now joined them in that position, and that **D. P. Markham,** who was Matthew Hall's Chief Instrument Engineer, becomes Air Trainers' Head of Industrial Products Division. Markham tells that they intend to apply their experience in simulating aircraft and engine dynamics—mechanical, hydraulic, electrical and electronic—to the dynamic investigation and simulation of process plant, particularly in the oil and chemical industries. 'Also, we anticipate developing certain specific industrial control equipment.'

Peter Lubbock who has left Dewhurst and Partner, where he was Publicity Manager, to join Evershed & Vignoles as Advertising Executive, holds pronounced views on technical advertising. He feels that 'new ideas are needed and possibly a lighter approach to the reader who is overwhelmed with a vast quantity of sameness in the advertising sections of his journals.'

Electro-Hydraulics, manufacturers of aircraft hydraulic equipment and fork-lift trucks, have set up an Industrial Hydraulic Sales Department under their Sales Director **L. Rumley.** He is also Sales Director of Conveyancer Fork Trucks—both companies are members of the Owen Organization. Rumley tells me that they intend moving more strongly into the general industrial field and that they have a team whose aircraft control experience qualifies them to undertake design, development and manufacture of hydraulic, electro-hydraulic and servo systems. **P. A. Evans** will be Industrial Sales Manager. I asked Electro-Hydraulics' Technical Director, **C. B. V. Neilson,** to expand on the company's policy. 'I should like to enter the general process control field,' he said, 'but feel this company's place lies between the signals provided by the instrumentation, and the mechanical work which results from those signals.'

LUBBOCK
A lighter approach?

RUMLEY
Hydraulic actuator

Fred Ferraris (Clerkenwell) who handle Swiss made precision equipment, including measuring and indicating instruments and synchronous motors, in this country tell me that **Paul M. Garnier** has been appointed General Manager of the company.

Bruce Peebles of Edinburgh have formed a Divisional Board of Management consisting of **William M. McKenzie** (Administration), **R. W. Flux** (Transformers), **D. McDonald** (Engineering), **J. H. P. de Villiers** (Rotating Plant), **N. L. Jones** (Sales), and **J. W. Haig-Ferguson** (Electronics). **C. Phillips** has been appointed General Works Manager, and **G. Anderson,** Assistant General Works Manager. **J. S. Baillie,** Publicity Manager, told me that the electronics department has doubled its capacity since it was set up in September 1957, and is extending its influence in the field of automatic control.

Pick-off

by 'UNCONTROLLED'

'AUTOMATION Today and Tomorrow' is the title of Leonard Landon Goodman's new book which is to be published towards the end of the month. A good title, and one which set me thinking about other technical books using the 'today and tomorrow' idiom. I can only recall 'Television today and tomorrow,' which I think was published at the end of the war. Probably the growth of automation in the next fifteen years will be as spectacular as that of television in the last fifteen. But Goodman's book itself seems to attempt too much and therefore give too many disconnected snippets of information. Directed towards industrial readers, it strays into subjects such as research and salesmanship—in fact it is really a collection of notes for the industrial manager in the automation age. There is no proper theme. It is however easy to read and gives good advice, such as that about consulting research associations. Moreover it contains some useful case histories—which would have been improved by logical classification—a bibliography of 854 items (hardly anything after 1957), and an apt quotation from J. S. Mill. Nevertheless, from the copy of the book I have seen, I feel that it is not up to the standard of the author's successful Pelican 'Man and Automation.' (At £2 it is certainly not such good value.)

AS so often at exhibitions, I did not allow myself time to do justice to the wealth of engineering equipment on show at the Engineering, Marine, Welding and Nuclear Energy Exhibition, held at Olympia last month, though not very much was instrumentation or control equipment. But I was pleasantly surprised to find one stand entirely given up to control: the Navy's—their theme being 'Automatic and Remote Control in Naval Engineering.' Displays—some working—included automatic boiler control (now being fitted in one or two ships of the fleet), a boiler flame failure unit (under development), remote power control of a weapon launcher, a hydraulic speed governor for turbine-driven fuel oil pumps, and powered flying controls. Cmdr. Hodges, the officer in charge of the stand, told me that attendance had been good but it would have been better if the exhibit had not been indexed under 'Admiralty' in the catalogue. 'People have difficulty in finding us,' he said. (Certainly I took a little time, having looked up 'Naval' and 'Royal'.) But I hope their Lordships will give the engineering public a second chance to see an exhibit of this kind by putting an up-to-date version on at the IEA show next year. The present exhibit is being broken up as parts of it are required for naval training.

In my brief tour of the exhibition I heard the usual complaints about lack of publicity. Judging by the number of Press cuttings pinned up at the entrance, I am sure the trade and technical Press could not be fairly accused of neglecting it. It seems to be extra national publicity that exhibitors at the trade shows seek.

THE new AEI recruiting film *On Course with AEI* is first-class. Especially good are the opening scenes at an old car rally in the mud, ending in a picnic on a car's bonnet with real sandwiches

to explain the idea of sandwich courses. But somehow I missed the explanation—if there was one—of the difference between the 'thick' and 'thin' sandwich courses.

On Course with AEI—not such a good title as the IEE's *The Inquiring Mind*—traces the experiences of three student apprentices at the works of Metropolitan-Vickers (Manchester), BTH (Rugby) and Siemens-Ediswan (Blackheath). There are excellent shots of these students being instructed by senior craftsmen, in the lecture room, and enjoying themselves out of school. And a fascinating aspect of the film is that—unlike *The Inquiring Mind*—none of the actors is a professional. They are all AEI employees—even the three principal players, the youngest of whom is seen alongside a lathe at Manchester in the 'still' reproduced here.

IS it a sign of the times that CONTROL's American contemporary *Instruments and Automation* has recently changed its name to *Instruments and Control Systems*? 'Automation' of course has never widely caught on among engineers. Moreover in the flush of enthusiasm a few years ago too many periodicals added the word to their titles. Yet it has a connotation for the user that 'control engineering' or 'control systems' certainly does not possess. When the central training centre, discussed in the March issue, is established, I should prefer 'National Automation College' to 'National Control School' as its name. *The Times*, I note, has recently reported on a 'National Control (or Automation) College.'

WHEN in Nottingham last month, I dropped in at the small exhibition of boiler instruments which James Gordon & Co were holding in a hotel room. Rather sensibly the exhibition was open only in the evenings, for four days. Mr. Fisk, the firm's Sales Manager, told me that this idea of a provincial exhibition was experimental, and depending on its success, it might be repeated in other large towns.

Certainly a good deal of interest was being shown at Nottingham by local instrument and plant engineers. Personally I often find the small one-firm exhibition rewarding; at Nottingham my attention was caught by a display of some of the Swartwout electronic process control equipment. James Gordon are now applying this to combustion control, and a boiler at the Kingston Power Station is being fitted experimentally. The thermal power station will attract much electronic instrumentation in the years left before it goes the way of the steam locomotive.

NEWS ROUND-UP

from the world of control

—ATOMIC ENERGY—

Thermonuclear research

As CONTROL went to press, the IEE in conjunction with the British Nuclear Energy Conference, were holding their long-awaited Convention on Thermonuclear Processes. Although hardly of pronounced control engineering interest, the subject is quite fascinating. The complete proceedings of the Convention containing the full text of all the papers, lectures and reports of the discussion will eventually appear in a Supplement to the Proceedings of the IEE.

Switching and control

Several of the 20-odd papers did have some bearing on control, however. 'The Ignitron as a Switch in High-voltage Heavy-current pulsing circuits,' by Knight, Herbert and Maddison of BTH, was one of a number of papers concerned with switching requirements in capacitor discharge circuits in controlled fusion reactors (a new abbreviation: c.r.f.) of the Zeta type. Smart of AERE in 'Some Switching Problems in Thermonuclear Research' discussed the same problem: that of transferring a large amount of energy quickly from an energy store to an inductive load, and then maintaining the load current at or near its peak value for a comparatively long period. 'Switching and Control' by Bird of Metropolitan-Vickers described a compressed-air-operated mechanical switch which was designed for Zeta and initiated several hundred thousand discharges before it was replaced by ignitrons. Bird's paper gave some details of Zeta's control equipment: the rotating drum type sequence timing equipment, the control console, the electronic timing equipment, the two main control boards—one for the primary side of Zeta and the other for specialized measuring equipment, and interlocks and protection.

'Vacuum System Design' by Blears and Grear, also of Metro-Vick was of distinct control engineering interest.

It will be appreciated that the few papers mentioned are on the fringe of the subject. Do read the full report if you can spare the time.

—OIL—

Computing spirit blends

Motor spirit blends produced at British Petroleum's Kwinana, Western Australia, refinery are now being formulated using an inexpensive analogue computer. Designed in this country by a senior BP chemist, S. W. Adey, the computer is strictly a gasoline blending simulator. The proportions of the various ingredients, say catalytically reformed naphtha, catalytically cracked spirit, straight run components etc, are fed in on separate controls, and the octane number is indicated on a dial. The machine simulates the blending operation and has been tested and found to agree with 145 actual blends. Multi-grid electronic valves are used to introduce the non-linearities associated with gasoline blending.

CONTROL understands from Mr. Adey that his methods are considered somewhat unorthodox by some electronic engineers, and that many refinery engineers are biased against computing techniques. In order to prove the point, an experimental model is being built by Nash and Thompson and this will be installed in one of BP's UK refineries.

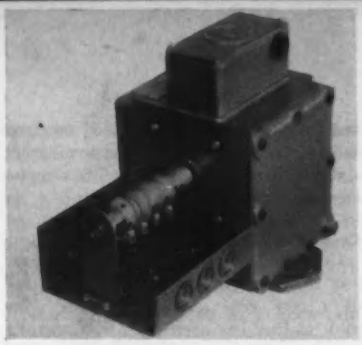
Mr. Adey is now experimenting with yet a further and rather more ambitious, prototype which is dry-battery powered. This will not only blend for octane number, but also for such other parameters as ease of ignition. He feels that there is a definite requirement for portable, inexpensive special purpose electronic slide rules for run-of-the mill routine calculations in engineering. The Australian model cost around £120—rather less than the stabilized power unit it employs.

MORE ATOMS FOR PEACE. The pile control room of No. 1 reactor at Chapelcross Nuclear Power Station, near Annan, Dumfriesshire, Scotland, which was officially opened on May 2nd. The Station has four reactors identical with those at Calder Hall. No. 1 reactor started working early this year and fed power into the grid for some weeks prior to the official opening

—AIR CONDITIONING—

$3·5 million order

The US Air Force bases in the UK are to be linked by a mobile microwave telephone and telegraph communication system which has been ordered from Marconi's Wireless Telegraph Co. with whom are associated the Automatic Telephone & Electric Co. Ltd. The system, which will cost around $3·5 million, will consist of a number of self-contained mobile stations each with its own power supply —Diesel alternator equipment is by Austinlite Ltd. The Marconi radio equipment operates in the 4000 Mc/s band, is capable of carrying 240 telephone channels, and incorporates an English Electric Valve travelling wave tube. Telephone equipment is by ATE and will operate in the 60 kc/s–552 kc/s band, and the telegraph channelling equipment will be provided by ATE



Semi-trailer vans carrying the US Air Forces new British $3-5 million communications system (Marconi's) will be air conditioned by Thermocontrol Installations. This step controller provides sequential operation of microswitches to control heaters and coolers

associates, the Telephone Manufacturing Co. Ltd.

Trailer air conditioning

The radio and channelling equipment will be accommodated in semi-trailer air-conditioned vehicles. Thermocontrol Installations Co. Ltd. will install hermetically sealed refrigeration units with automatic control by modulating thermostats, as well as by high-limit humidity control, in these vehicles. All the air conditioning equipment will be controlled by thermostats and humidistats, and the dehumidification, heating and cooling controls are interlinked to avoid overrun and waste of power.

The control system includes the step controller (illustrated) for graduated and sequential control of the electrical heater batteries and refrigeration condensing units. The step controller incorporates a shaded-pole reversing motor which transmits through a gear train to a camshaft. This provides sequential operation of a series of microswitches which control a battery of heaters and coolers.

The humidistat—a hair hygrometer—is highly sensitive and provides control action at the slightest change in humidity. Temperature control is by a vapour pressure type controller, having throttling band adjustment in addition to the main setting.

—MINING—

Colliery control

The Scottish Division of the National Coal Board have ordered a new type of colliery control equipment from Bruce Peebles of Edinburgh, for installation in several new shafts. The first is expected to be installed at Killoch Colliery, Ayrshire, before the end of the year.

The news followed the announcement of an agreement between Bruce Peebles and Simon-Carves of Stockport, for the joint design and supply of colliery control equipment. The equipment concerned is electronic-pneumatic and electronic-hydraulic control and interlocking equipment for mine car handling, skip winding plant and other mining applications.

A contactless system

Both companies are experienced in mining requirements and in electronic control. Their joint efforts have now resulted in the development of a 'completely contactless control system'. The equipment is said to be reliable under the most adverse wet, humid and dusty conditions.

At a recent private exhibition by Bruce Peebles of the products of their Electronics Department, a control desk for the skip winding equipment was shown. Other exhibits included a warp inspector for detecting faults in made-made fibres, a pinhole detector for use in strip mills, analogue computer units, static switching systems and a linear transducer.

—DATA PROCESSING—

Perseus for Sweden

The Ferranti Perseus digital computer, ordered by the Trygg and Fylgia Insurance Companies of Stockholm, has passed its final acceptance tests at Ferranti's Bracknell Laboratories and is now in Sweden. The illustration shows part of the dismantled machine prior to shipment.

Costing £300,000 and the largest data processing machine yet made in Western Europe, this is the first of two Perseus systems, which Ferranti are exporting. The second machine is near completion at the company's West Gorton factory in Manchester. It will soon be shipped to South Africa for installation in the South African Mutual Life Assurance Society Building in Cape Town.

IBM 704 translates Braille

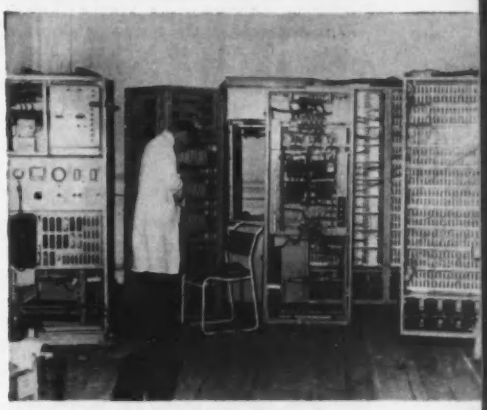
A process for translating printed text into Braille with the aid of a digital computer has been developed by IBM and the American Printing House for the Blind. Using an IBM 704, a 300 page book can, it is said, be translated into Braille in an hour.

Texts to be translated by the computer are first transcribed onto punched cards. The cards are then fed directly into the computer, which has had previously stored in its memory a programme for conversion of English into Braille. Contractions and abbreviations are determined by matching the letters involved against an alphabetical table of Braille equivalents. The translated text emerges from the computer in coded symbols on punched cards, and these, in turn, are fed to the 704's printer unit which reproduces Braille symbols above the English text for editing purposes. After editing, the corrected punched cards are fed into an embossing machine which produces metal plates ready for use in a rotary press.

CONTROL understands that in order to speed the work, printed texts will be recorded on magnetic tape and distributed to IBM computer installations where they will be translated, and the cost borne by IBM.

US-France computer agreement

The Intertechnique Company of Boulogne-Billancourt, near Paris, a subsidiary of France's largest aircraft company, General Aéronautique Marcel Dassault, has signed an agreement with the Thompson-Ramo-Woolridge Products Co. of Los Angeles, to manufacture and sell the latter's RW-300 digital control computer in France. In addition,



Part of a Ferranti Perseus digital computer being dismantled prior to shipment to Sweden

Intertechnique will handle the systems engineering, field engineering and other services equivalent to those provided by TRWP in the US and elsewhere.

Nuclear data-logging

Intertechnique has a contract from Electricité de France, to furnish a computing data-logging system for the first French commercial nuclear power station which is being built near Chinon. The system is to incorporate two RW-300 computers and will monitor the 1148 fuel cartridges in the EDF-1 reactor.

The entire system, including radiation detectors, computers and other electronic and electromechanical equipment, is expected to cost about $530,000. It will detect and locate pinholes, splits and other faults in fuel elements, and print-out data and actuate alarms.

—STEEL—

Port Talbot strip mill

The Steel Company of Wales' new rolling mill, whose control was discussed in 'Control in Action' in February, have allowed further details to be released.

The operator in the buggy pulpit, at the Steel Co. of Wales' Port Talbot works, has 15 TV monitors to enable him to see the remote handling of ingots. He controls rail cars on 100 ft of track, 700 ft of which are covered by the closed circuit TV installation

It may be recalled that one of their problems was to feed the new universal mill with ingots at a rate fast enough for the mill to develop its full potential. After the steel ingots are cast, they are brought to a uniform temperature in soaking pits. Previously, an ingot was taken from the pits by a crane and placed on an ingot buggy which carried it to the mill. They were unable to feed the mill fast enough using that system, so an additional vehicle, called the shuttle car, now operates between the buggy and the mill.

The buggy is positioned opposite a pair of soaking pits from which ingots are to be drawn, and the shuttle car is brought up to the buggy. The crane places an ingot in the buggy, the ingot then being passed to the shuttle car, as is a second ingot. The shuttle car runs to the mill while the buggy continues operations at other pairs of soaking pits.

Remote Control

Both shuttle car and buggy are controlled from the buggy pulpit and the two vehicles may meet at any point up to 1000 ft. from the operator in the pulpit. Furthermore, the two vehicles close each other at very high speeds. The operation of buggy and shuttle car is synchronized with the aid of signals from potentiometers. One potentiometer system is controlled by a torquemeter operated by a cable towed by the buggy, and the other system is controlled from the shuttle car winches.

Remote viewing by 15 TV channels

The operator in the buggy pulpit must be able to see the transfer of ingots throughout the several hundred feet of track over which the two vehicles may meet. In order to provide this remote viewing, 15 closed-circuit television channels are employed. The system, which is by Marconi's Wireless Telegraph Co., consists of 15 cameras installed along the track and 15 viewing monitors in the buggy pulpit. The cameras are mounted in line on one of the outside walls of the building, and look in and down at the rail track. Each camera has a wide angle lens and surveys some 45 ft of track, so that about 700 ft of track is covered. The separate camera outputs are fed to control racking and thence to the 15 monitors in the buggy pulpit.

CONTROL gathers that this installation posed some unusual problems, notably the low level of light in the area and the high ambient temperatures (over 160°F) which occur. The Port Talbot works operate on a 24 hour basis, so the TV installation is expected to stand up to continuous use.

FUEL

BCURA comes of age

The British Coal Utilization Research Association at Leatherhead threw open its doors to members and visitors for three days recently, on the occasion of its 21st anniversary. The guest of honour was the Minister of Power, Lord Mills. Many excellent demonstrations and exhibits showed the various developments sponsored by the Association since its inception.

BCURA is one of the largest of the 39 industrial research associations supported by DSIR, and in 1958 its income was £413,000.

At present BCURA is primarily concerned with three fields of research: problems arising from the need to use small coals; an increasing need for coal to compete more strongly with oil fuel; and problems arising from the implementation of the Clean Air Act.

Coal gasification

One of the surprises of the Open Days was the unveiling to general inspection of a new coal gasification plan. This pilot gasifier has been built by Constructors John Brown on the same site as the BCURA laboratories, CJB having received a contract from the Ministry of Power. The first hot run was made in June of last year and since then there has been steady development under CJB's Chief Chemical Engineer, Mark Guter.

The main purpose of the pilot gasifier is to find any snags inherent in the operation of a fixed-bed slagging gasifier at pressure. The novelty of the project lies in the pressurizing unit, which operates at 100 lb/in² gauge.

The plant is fully instrumented. Panellit data-logging is used in combination with a Creed puncher for feeding the results into a digital computer—not at Leatherhead. The control room has five recorders and a panel from which 16 plant variables are set and controlled automatically.

CONVEYING

BR use driverless trucks

As reported in March, British Railways have ordered the Robotug driverless truck from EMI Electronics. In this system the trucks are guided along a single cable, laid just beneath the flooring, which has about ½ amp. a.c. passed through it. A safety bumper, fitted to the front of the truck, will halt the vehicle if an obstruction is met, by opening a microswitch to de-energize an interlock relay.

Trials at Newton Abbot goods shed

The Western Region of British Railways are experimenting with two Robotugs—standard railway platform trucks

A Robotug driverless truck hauling a train of trolleys follows its guidance wire at British Railway's Newton Abbot goods shed. Nine experimental tracks have been laid

by Scott Electric Vehicles—at Newton Abbot goods shed. They have carried out durability tests consisting of hauling a 3-ton load continuously for 2 to 3 miles at around 2 miles/h, in order to prove the 121 ampere/hour battery capacity adequate for the work carried out in an 8-hour shift.

Nine guidance tracks have been laid ½ in. below ground, and overhead push-button panels enable the dispatchers of tugs and trains to direct the driverless vehicle to any given point in the shed.

LIGHTING

TV lighting control

At a recent demonstration by Strand Electric and Engineering, to television lighting supervisors, which CONTROL attended, two new prototype control equipments were unveiled for comment.

This television lighting control console is part of a Strand Electric set-up which incorporates a punched-card memory

Neither device is in production and we understand that the reason for the demonstration was to give a foretaste of what may be available within the next year or so and also to obtain the reaction of potential users. One equipment, Strand's KTV control, incorporated a Hollerith punched-card memory, and the other the SD/WH all-electric dimmer, employed silicon controlled rectifiers or 'thyristors'.

Punched-card memory

Strand's KTV control provides a memory via Hollerith cards so that a lighting effect once obtained in rehearsal, can be infallibly repeated. The operator at the console, illustrated, can set up a lighting situation—dimming as well as switches—'punch' it and it is then held on a card or cards for future use. Despite the fact that manual overriding by the operator is easily applicable, TV lighting supervisors present, seemed rather dubious about the use of punched cards—not always, in CONTROL's opinion, on particularly valid grounds. A standard Strand electrochemical dimmer bank was used.

Thyristor-controlled dimming

Much interest was expressed in a lightweight and compact electronic dimmer, the prototype SD/WH. This operates in thyratron fashion, a variable proportion of the a.c. sine wave being used to give steplessly variable light levels. This 'clipping' means that present filament lamps tend to 'sing'—a great drawback in a television studio. The two power semiconductors used, were obtained from American GE and CONTROL understands that at present they cost some £60 each, although there is every indication that this price will come down radically when thyristors are available from British sources. Possibly the forthcoming transistor exhibition will shed some light on this matter. The GE thyristors used in Strand Electric's prototype dimmer enable 5 kW to be *switched* although for dimming purposes, 2 kW at 230 V a.c. is as much as can be expected.

Fusing troubles

One reason why Strand have had to limit their new dimmer to 2 kW is because they are unable to obtain fuses with a fusing constant better than 40 (fusing constant is milliseconds-to-fuse-blow, times current). As they are limited to a peak current of 125 amp the only fuse available with a time constant of 40 is a continuously rated 5 amp fuse. Fusing problems of this nature are becoming serious in the semiconductor world.

IN BRIEF

● **Canadian** Department of Defence Production has ordered $200,000 worth of telecommunications measuring equipment from Marconi Instruments Ltd, through the latter's Canadian agents, Canadian Marconi Co.

● **Crypto** Ltd (a Lancashire Dynamo Company) have transferred their Leeds branch to Leylands Rd, Regent St, Leeds 2, under Branch Manager W. M. Swain.

TURBIDITY CONTROL. Automatic process control by measurements of turbidity or absorption is provided by this Sigrist and Weiss photometer which Southern Instruments handle in the UK. The system is one in which two light beams emanating from the same source are compared by a single photocell, the beam being alternated between specimen and standard by an oscillating mirror

● **Standard Automation Products,** 1738 Ridgeway Road, Havertown Pa., USA (Mr Leonard M. Wasserbly) wants quotations and samples of British electrical and mechanical products. Wanted are small hand and power tools, testing devices, electrical instruments and components selling at under $100.

● **Mullard Research Laboratories,** at Salfords, Surrey, are being enlarged some 45,000 sq. ft. Two new blocks will house the electronics, telecommunications, transistor applications and television laboratories, and also improve facilities for research into valves, semiconductors and materials.

● **'Instrument Construction,'** a translation of the Russian monthly journal *Priborostroenie* is being produced by BSIRA for DSIR. Publishers: Taylor and Francis Ltd, Red Lion Court, Fleet Street, London, EC4.

● **Emiac II:** a two module version of EMI Electronics' Emiac II analogue computer has been ordered by the Australian Government Aircraft Factory, Melbourne. Another Emiac II, understood to have cost around £55,000, has been dispatched to Sir W. G. Armstrong Whitworth Aircraft and should be in operation in July.

EDUCATION

A CONFERENCE REPORTED

Automatic control fundamentals

A Conference, 'Teaching the Fundamentals of Automatic Control', organized by the Institution of Mechanical Engineers and Cambridge University's Department of Engineering, which was held in Cambridge last month, may have far reaching effects on the future of control engineering in this country.

The object of the Conference, whose membership was restricted to those engaged in teaching at Degree and Dip. Tech. level, was to provoke thought on the influence which control theory and related topics should have on the education of mechanical engineers, and more particularly on the teaching of applied mechanics and mechanics of machines.

The two-day meeting consisted of three discussion sessions and a course of six lectures, designed to instruct those new to the subject and to present the fundamental principles in a form appropriate to an honours syllabus in mechanical engineering. The lectures, given alternately by Dr G. D. S. MacLellan and Dr P. E. W. Grensted, were entitled: 'Some fundamental concepts';

'Characteristics of simple closed loop systems'; 'Linearized analysis, with particular reference to speed control'; 'Frequency response'; 'Theory of controller design'; 'Some advanced topics'.

Syllabuses heavily loaded

The lecturers suggested that the material presented in the first five of these represented the content of about 10 lectures at undergraduate level, assuming that the necessary mathematics—little more than in existing syllabuses—could be covered elsewhere and that more worked illustrative examples would have to be fitted in. The presentation of this material was done without resort to the Laplace transform. Although this might mean that undergraduates could make less use of American textbooks, it was argued that the most important thing was to get across the basic principles of feedback and control system components. With syllabuses already so heavily loaded, students were disinclined to make the extra effort to master new ideas *and* new mathematical techniques simultaneously.

In the discussion which followed it was interesting to find that some members of the Conference favoured much earlier teaching of the theory of pneumatic and hydraulic controllers in illustration of the feedback principle—perhaps by analogy with feedback amplifier theory. Thus automatic control systems would be treated as, in effect, a special type of feedback amplifier with unity negative feedback.

The three discussion sessions were opened by visiting speakers. Dr J. H. Westcott spoke on 'Analogue Computers as Teaching Devices'. As an electrical engineer amongst mechanicals, he was careful to choose appropriate illustrations, including computation and display of wave propagation and the modes of oscillation of two-degree-of-freedom systems. Professor R. H. Macmillan spoke on 'Automatic Control Theory as Part of an Honours Course', and was able to quote from an article with this very title which he had published nearly ten years ago. The problem now was not so much 'Should it be taught?', but 'How should it be taught?'.

Mechanicals and autocontrol

Finally there was a discussion on 'The Task of the Mechanical Engineer in Industrial Applications of Automatic Control'. Mr W. H. Pearse, of British Oxygen (Gases) Ltd, who has much experience in the development of precision position controls, urged the need for closer integration of mechanical and electrical teaching. Mr S. D. Lyon, of ICI's Wilton Division, also spoke of the need for engineers with a broad training who could work in a team with chemists, physicists, chemical engineers and instrumentation and control specialists. Mr D. B. Welbourn, of the Cambridge University's Engineering Department, spoke of his experience of speed control and governing problems in industry, and suggested that with quite simple techniques drawn from modern control theory most valuable results could be achieved. The need was for engineers trained in the fundamentals and with the ability themselves to instruct the men on the job.

The chair at this session was taken by Mr E. Bruce Ball, Member of Council and of the Education Committee of the Institution, and the meeting was attended by the President of the Institution, Air Marshal Sir Owen Jones.

Mathematics difficult?

There were, of course, many differences of opinion about details of syllabus and methods of presentation. Certain fears were expressed about mathematical requirements, and the importance of laboratory work to accompany lecture courses was stressed. But the meeting as a whole was a most encouraging example of the possibilities of fruitful co-operation between a university engineering department and a major professional Institution, in these days when technological developments make necessary a new approach to education.

G. D. S. MACLELLAN

'Teaching the fundamentals of automatic control': Dr MacLellan talks to a group of delegates in the Hydraulics Laboratory

LOOKING AHEAD

A diary for the next three months

Unless otherwise indicated, all events take place in London. BCS British Computer Society. BritIRE British Institution of Radio Engineers. IEE Institution of Electrical Engineers. RAeS Royal Aeronautical Society. SIT Society of Instrument Technology

MONDAY 11—WEDNESDAY 13 MAY
Joint Symposium on Instrumentation and Computation in Process Development and Plant Design. Details: General Secretary, Institution of Chemical Engineers

TUESDAY 12 MAY
Early Experiences with an EDP Installation. T. C. Hickman, BCS 6.15 at the Northampton College of Technology, EC1

THURSDAY 21—WEDNESDAY 27 MAY
International Convention on Transistors and Associated Semiconductor Devices. There will be a technical exhibition associated with the Convention. Earls Court.

MONDAY 25 MAY—THURSDAY 4 JUNE
Business Efficiency Exhibition, Olympia

MONDAY 15—SATURDAY 20 JUNE
International Conference on Information Processing. Organized by UNESCO in Paris. Details: Hon Secretary, Group B, BCAC, c/o IEE, Savoy Place, WC2

TUESDAY 16—TUESDAY 30 JUNE
International Electronic, Nuclear and Cinematographic Exhibition, Rome

WEDNESDAY 17—SATURDAY 27 JUNE
International Plastics Exhibition and Convention. Olympia

MONDAY 22—THURSDAY 25 JUNE
1st British Computer Society Conference, Cambridge

WEDNESDAY 1—SUNDAY 5 JULY
Television Engineering in Science, Industry and Broadcasting. BritIRE 1959 Convention, Cambridge

MONDAY 6—FRIDAY 10 JULY
Conference on X-ray analytical methods, Imperial College of Science and Technology, London, SW7. Details: The Conference Secretary, Research and Control Instruments Ltd, 207 Kings Cross Rd, London, WC1

THURSDAY 9—WEDNESDAY 15 JULY
14th Annual Electronics Exhibition and Convention. College of Science and Technology, Manchester

LOOKING FURTHER AHEAD

WEDNESDAY 26 AUGUST—SATURDAY 5 SEPTEMBER
26th National Radio and Television Exhibition. Earls Court

MONDAY 7—SATURDAY 12 SEPTEMBER
SBAC Flying Display and Exhibition, Royal Aircraft Establishment, Farnborough

OCTOBER 1959—SEPTEMBER 1960
Graduate Courses in Information Engineering and Theory of Electrical Machinery (which includes sections on automatic control systems). Details: The Graduate Course Supervisor, Electrical Engineering Dept, The University, Edgbaston, Birmingham 15

MONDAY 5 OCTOBER—FRIDAY 8 JULY 1960
Postgraduate Course in Control Engineering. Applications to The Warden, College of Aeronautics, Cranfield, Bucks

TUESDAY 6 OCTOBER—JUNE 1960
Postgraduate Course in Control Engineering. Applications to the Secretary, Cambridge University Department of Engineering, Trumpington St, Cambridge, not later than 1st July

MONDAY 12—FRIDAY 16 OCTOBER
Pneumatics & Hydraulics for Industry Exhibition and Convention, Alexandra Palace

TUESDAY 10—SUNDAY 15 NOVEMBER
International Exhibition of Laboratory, Measurement and Automation Techniques in Chemistry, Basle. The Association of Swiss Chemists in collaboration with the Swiss Association of Automation will hold concurrently a scientific Congress covering the same fields.

TUESDAY 5—THURSDAY 7 JANUARY 1960
Symposium on recent mechanical engineering developments in automatic control. Details: The Secretary, The Institution of Mechanical Engineers, 1 Birdcage Walk, Westminster, London, SW7

New for Control

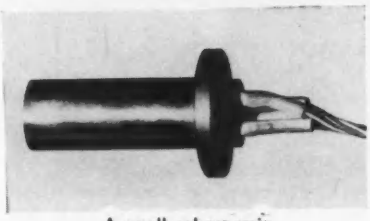
A monthly review of system components and instruments

PRESSURE TRANSDUCER

employs a new principle

The vibrating cylinder pressure transducer employs a new design principle and is small, accurate and robust. The variable frequency output signal makes it suitable for magnetic tape recording, also for analogue-to-digital conversion by pulse counting.

The input pressure ranges are 25, 50, 100 and 600 lb/in² gauge. The terminal linearity and hysteresis is ±1·5%. The fundamental response follows a parabolic law curve and the repeatability on this curve is accurate to ±0·1%. The excitation is from a miniature



A small robust unit

6V transistor feedback amplifier. There is a high and a low output impedance. The thermal coefficient of sensitivity is 0·02% of range /°C. The dimensions are 1·5 in. dia. and 2·5 in. long, with a weight of 2 oz.

The Solartron Electronic Group have concluded with the Svenska Flygmotor Aktiebolaget a manufacturing and marketing agreement of world-wide coverage for this pressure transducer.

Tick **No 171** on reply card

PRECISION POTENTIOMETER

the smallest yet

The type 8 model precision potentiometer from Ferranti Ltd measures ¾ in. in diameter and has a shaft diameter of 0·078 in. It weighs 0·5 oz and the makers claim it is the smallest wirewound precision potentiometer in 3-gang form yet produced in Europe.

Resistance values range from 1 kΩ to 25 kΩ, the tolerance being ±5%. Power rating is 1 watt with no derating up to +70°C. The models available include linear, sinusoidal and non-linear functions, the standard linearity tolerance being ±0·3%, but this can be made as low as ±0·1%.

The toroid, which is made of anodized aluminium, is housed in a stable plastic moulding contained in a machined aluminium body. The shaft is mounted in precision miniature ballraces, which, coupled with low wiper pressure, ensure a low operating torque of the order of 0·5 g/cm. The wiper or sliding contact is formed from precious metal wire, a double contact being used for greater reliability; the wiper pressure is of the order of 1 g.

Tick **No 172** on reply card

CONVERTER

a transistorized unit

Venner Electronics Ltd have designed a transistorized megacycle converter (type TSA5) for use with their frequency meters type TSA3 and TSA53. It enables measurements to be made up to a frequency of 1 Mc/s on 100 kc/s instruments, or up to 500 kc/s on 50 kc/s instruments. The converter consists essentially of a scale-of-ten transistor megacycle divider preceded by a megacycle pulse shaper and emitter follower stage presenting a high input impedance to the signal. An input attenuator and a stabilized mains power supply are included. The dimensions of the unit are 6×6×7 in.

Tick **No 173** on reply card

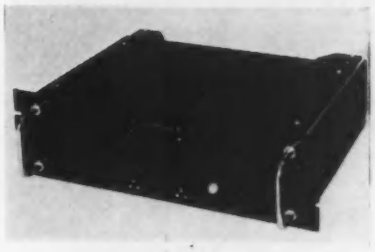
INTERVAL TIMER

an aid to process control

The interval timer (type NE068) was originally developed for the control of slow scalers (type NE075), but can be used to control any process which can be initiated by either a short exponential impulse or the operation of a change-over contact, and terminated by a second impulse or the return of the change-over contact to the original position.

Pulses from a hermetically-sealed electromechanical timing unit are fed at a rate of four per second 'scale of four' to provide output impulses at a rate of one per second. The timing unit starts automatically when the unit is switched on and is compensated over the temperature range —10 to +50°C.

The impulses operate an electromechanical counter which subtracts one digit per impulse from the preset time indicator. When the predetermined time interval has elapsed the change-over contacts are operated and the unit remains in the 'ready' state. If the external connexion between start terminals is still made counting will recommence as soon as the reset signal has been applied. If the external connexion is not made it will be necessary to provide a reset signal and a start signal. An 'adding' counter can be fitted in addition to the 'substracting' counter to provide an indication of elapsed time. The unit may be operated manually from switches on the front panel, or by remote control.



The front panel of the timer measures 19 × 5½ in.

The timing range is 1–9999 sec in 1 sec steps with a maximum error of 40 msec. The contact rating is 100 V at 300 mA d.c.

The timer is manufactured by General Radiological Ltd.

Tick **No 174** on reply card

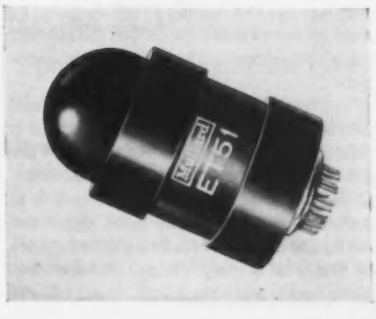
COUNTING TUBE

a high-speed stepping unit

Mullard Ltd have announced the introduction of a trochotron high-speed decimal stepping tube, for use as a counter or selector at speeds up to 1 Mc/s. The tube (type ET51) is switched by a negative signal, and provides a constant-current output of 5·5 mA; sufficient to drive a cold cathode decimal indicator (such as the Mullard Z503M) and compatible with the input requirements of direct read-out digital indicators.

The output characteristic of the trochotron is similar to that of a pentode valve, and in the ET51 over 80% of the beam

For speeds up to 1 Mc/s



current appears in the output, the remainder being used to form and lock the beam.

Typical operating conditions for the tube, which is a direct replacement for the American Services type 6700, are: *spade*: voltage 100 V; current 1·0 mA; load resistor 100 kΩ; grid voltage 25 V; input pulse 60 V; and cathode current 6·5 mA: *target*: voltage 100 V; output current 0·5 mA; and heater 6·3 V, 300 mA (a.c. or d.c.).

Tick **No 175** on reply card

CONDUCTIVITY BRIDGE

transistorized, battery-operated

A conductivity bridge from A. M. Lock & Co. is energized at a low potential from a 1500 c/s transistor oscillator. The high frequency is used to overcome inaccuracies which would otherwise occur at high solution conductivities. It operates from a long-life dry battery and

Good sensitivity, accurate

covers the range of 0·5 μΩ to 1 × 10⁶ μΩ in six steps. The bridge is housed in a wooden case 12 × 7½ × 5½ in., weighs 7 lb, and is supplied complete with a dip type conductivity cell.

Tick **No 176** on reply card

LOW FREQUENCY GENERATOR

models cover 0·0001 to 100 c/s

The main part of the low frequency generator from Servo Consultants Ltd consists of a resolver rotating with carefully stabilized angular speed. The output signal from it is rectified by means of a phase sensitive rectifier which removes the carrier component of the signal. The signal is applied to an attenuator and a cathode follower to produce an output signal with a low source impedance.

The resolver is driven through a two-speed gearbox by a servomotor-generator and a high gain servo amplifier. The output of the generator is applied as a velocity feedback to the input of the amplifier, where it is compared with a velocity input signal derived from an electronically stabilized supply by means of a chain of high stability precision resistors. The high gain of the amplifier ensures that the motor runs substantially at the speed corresponding to the voltage selected. It is possible to stop the generator at any point within the output waveform cycle. The generator will start from any preset position without introducing any transient. The starting and stopping is almost instantaneous as the servomotor is capable of very fast acceleration and braking.

The mechanical output of the generator is available in the form of a rotation of a shaft revolving with a speed of 1 rev/cycle. It can be therefore used as a precision variable speed drive for experimental laboratory use.

The frequency range is 0·001 to 100 c/s (model 110) and 0·0001 to 10 c/s (model 111). The output amplitude has a 30 V peak and the maximum output current is 10 mA. The output impedance is 250 Ω and the distortion 1%.

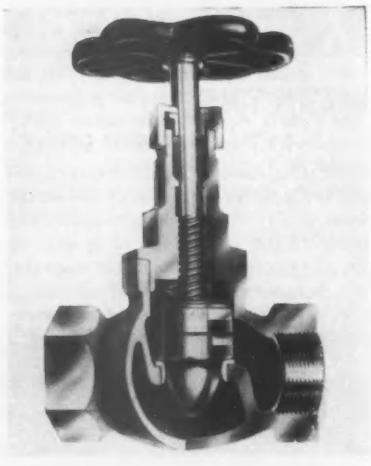
Tick **No 177** on reply card

STEAM CONTROL STOP VALVE

a unique design

A new control stop valve has been designed for controlling a flow of steam at working pressures of up to 300 lb/in² and temperatures as high as 500°F.

On initial opening the main valve is raised approximately $\frac{1}{16}$ in. clear of its flat seat, but the orifice remains sealed by a special spring-loaded parabolic plug. As the unit is opened more fully, the plug is gradually withdrawn from the orifice to provide a streamlined annulus for the passage of steam. This design makes it almost impossi-



A steam valve giving fine control

ble for foreign matter to be trapped on the main valve seat, and the fine degree of control—from minimum flow to full bore—allows steam to be admitted slowly to a cold system with full protection for the valve and seat against the direct cutting action of the high velocity steam, thus preventing wire drawing.

The valve is manufactured by Sir W. H. Bailey & Co Ltd.

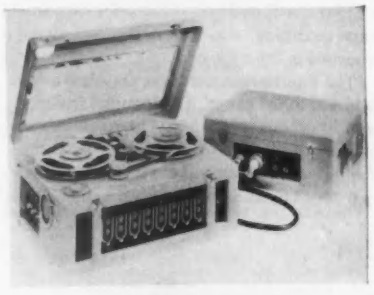
Tick **No 178** on reply card

TRANSPORTABLE RECORDER

for control and testing purposes

A range of Midas transportable recorders is being introduced by Royston Instruments.

The transportable recorder is made up of two basic units—the tape deck and electronics; and the stabilized power supply. It has a frequency range down to 2·5 and up to 100 cycles/in./sec maximum on FM coding, a minimum input for 100% modulation of 10 mV peak to peak a.c. ± 1V d.c. On direct record (speech) the frequency range is 1 kc/s/in./sec with a minimum input of 1 mV. For direct record (data) the frequency range is 1 kc/s/in./sec maximum with a minimum input of 10 mV. The input impedance is 1 megohm and 20 μμ F.



A compact portable recorder

The capacity of the tapes is 1800 ft and speeds can vary from 1/10 in. to 100 in./sec, in accordance with the maximum frequency required. The tape widths can be either ¼, ½ or 1 in. and the total number of channels can be either 4, 8 or 16 respectively. (In each case one channel must be reserved for reference in FM.) In addition the necessary facilities for remote control are provided with all the recorders in the range. The recorder varies in weight from 45 to 50 lb.

Tick **No 179** on reply card

NYLON COIL BOBBINS

for miniature transformers

George Goodman Ltd have introduced a stock range of nylon coil bobbins for miniature transformers in printed circuit and similar work. Initial sizes are for square stacks of MEA 187 (RCL 450), MEA 262 (RCL 531) and MEA 218 laminations. The bobbins are designed with universal slots for bringing out leads and a hole flush with the inside of former for the first tap.

Tick **No 180** on reply card

LOAD INDICATOR

can operate on low a.c.

An automatic load indicator unit (type ALI) has been produced by Electrical Remote Control Co. It operates when a.c. is passed through a choke in the unit, the voltage drop being used to

operate a relay (5 A contacts at 230 V a.c.) It can be supplied for maximum loadings of 20, 35, 50, 75 and 100 A at 250 V a.c. The minimum load detected can be 60 W at 250 W a.c. The units are capable of withstanding heavy overloads. The prices range from £6 5s and delivery can be effected within 2–4 weeks.

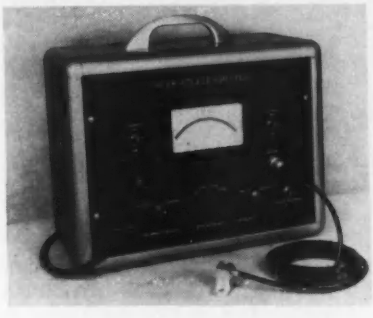
Tick **No 181** on reply card

PEAK ACCELEROMETER

the only one of its type

A peak accelerometer which is claimed to be the only portable instrument of its type produced in the UK has been made by Ferranti Ltd. It can also be used for measuring peak *g* values in vibration testing.

The instrument comprises two main units, a probe for fitting on the sample under test and an indicator unit. The latter incorporates a cathode follower, an a.c. amplifier, a low-pass filter with a cut-off frequency of 675 c/s, and an output socket for connecting a cathode-ray oscilloscope. It is also fitted with a double-scale, 3½ in. dial rectangular flush mounted indicator, with mirror scale and knife-edge pointer, giving four ranges of *g* units from 0–25, 0–100, 0–250 and 0–1000 *g*. Minimum readable *g* is 3. Manipulation of a switch on the instrument enables vibration readings from 8 to 750 c/s per second to be obtained.



The accelerometer can retain a reading to within 2% for 30 sec

The acceleration-sensitive element or probe consists of a barium titanate crystal accelerometer fitted in a metal housing. A sensitivity of 9 mV/*g* is obtained at the probe socket on front panel.

Weight of probe and 12 ft of cable is about 5 oz. The basic price of the peak accelerometer supplied with this length of coaxial cable is £212.

Tick **No 182** on reply card

ACTUATORS

a useful range for industry

A new hydraulic or pneumatic actuator is available in a servo or a non-servo form. The non-servo actuator is a one unit cylinder incorporating its control means within the cylinder, either for manual operation or for electric operation. Installation is simple in that only one pipe to power supply is necessary and one to exhaust. The control is by mechanical means, such as a cable, or alternatively by solenoid as part of the actuator.

In the servo actuator the valve is incorporated within the cylinder, together with its operating means and positive locking. The valves can be so adjusted that extension of the piston rod to any reasonable limit can be achieved at the time of manufacture. It is claimed to be the only servo cylinder available, for its size and price, for industrial purposes.

The hydraulic models have bore sizes of 1½, 3 and 6 in. with maximum working pressures of 3000, 3000 and 2000 respectively. The pneumatic models have bore sizes of 2, 4 and 6 in. with maximum working pressures of 400, 200 and 200 lb/in.² respectively.

The actuator is made by Turner Manufacturing Co Ltd and is sold through the sales subsidiary company, Hydraulics and Pneumatics Ltd.

Tick **No 183** on reply card

CONTROL VALVE AND CYLINDER

for pneumatic control

A double solenoid-operated control valve has been introduced by A. Schrader's Son. It operates or returns in response to momentary energizing of one or other of the solenoids. The solenoid unit is mounted pick-a-back fashion on the valve mechanism, giving a compact shape of moderate dimensions. It is available in five popular voltages and the coils are continuously rated.

The valve has a high air flow and low current consumption

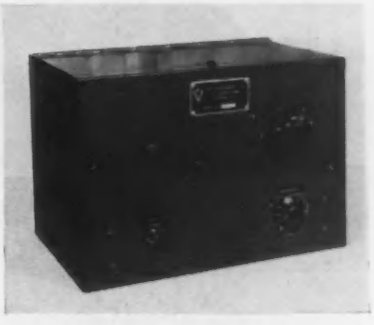
The same firm have added a 1 in. bore double-acting cylinder to their existing range. It has a 1 in. neck mounting thread, and is available in strokes of 1, 2, 3, 6, 9 and 12 in. The pressure range is 0–125 lb/in².

Tick **No 184** on reply card

TEMPERATURE CONTROLLER

an aid to furnace efficiency

The CNS Instruments saturable-reactor-type proportional temperature controller is fed from a resistance thermometer. The thermometer's change of resistance with temperature is used in a bridge system to give a continuously variable current which governs the output of a saturable reactor or transductor. This controlling current varies from 5 to 100 mA d.c. with a load of 2500 Ω maximum.



Has been used for creep test furnace temperature control

The controller is used in conjunction with a reactor of suitable size for the particular furnace. Used with a 1 kVA reactor, the power supply to a furnace can be set from 200 VA to 1 kVA by adjustment of the bridge precision potentiometer. After this setting, any variations in the resistance of the thermometer due to temperature changes in the furnace will readjust the current to maintain constant temperature. A 1% change in absolute temperature is sufficient to swing the control current from its maximum to its minimum value, and temperature errors which would occur without the controller are reduced by a factor of 600 approximately, whether they are due to mains voltage variations, ambient temperature changes or varying thermal constants. This means that the overall effect of a mains voltage change of 5% on a furnace operating at say 700°C can be reduced to within ±0·2°C.

Tick **No 185** on reply card

ELECTRIC RELAYS

polarized and multiple types

An improved Carpenter polarized relay (type 521) will shortly be available from Telephone Manufacturing Co. Ltd. Used as a chopper at 50 c/s, virtually no change of adjustment should be necessary due to mechanical wear, within 2500 hours. Used as a d.c. relay, great improvement in stability is claimed to be achieved by a redesigned contact

Now **Kent-Barton** Mercuryless Instruments join the **Commander** range

Commander Kent-Barton instruments, showing (cut-away) the patented Barton differential-pressure unit

for wet gas

for corrosive fluid

for off-level mounting

Mercuryless differential-pressure instruments for flow and other variables are the latest additions to the wide KENT *Commander* range. These have certain advantages over the mercurial types wherever wet gas or corrosive fluid is to be measured or where level mounting is difficult or impracticable. Models available are either circular-chart recorders, sector-scale indicators (automatic control optional); or circular-scale indicators. Optional recording of Bourdon-tube pressure and/or mercury-in-steel temperature also available in addition to primary variable.

Commander mercuryless instruments incorporate the Barton patented differential-pressure unit. Although the actuating element is a sensitive bellows, pressure differences as high as the pressure rating of the instrument can be sustained without damage to this rupture-proof unit.

some features

Choice of six maximum differential pressures: 50 to 400 in. w.g. Standard safe-working pressure: 2500 lb/sq. in. Controlling unit: KENT air-operated one- two- or three-term *Mark* 30 series within the instrument. Pressure elements up to two Bourdon tubes for pressures 3500 lb/sq. in. to 30 in. mercury vacuum. Temperature elements: mercury-in-steel with limits from -40°F/-40°C to 1100°F/600°C
Mounting: wall, panel or post
Write for Publication 354, or telephone General Industrial Contracts Dept. (Luton 2440, Ext. 8) for a quotation.

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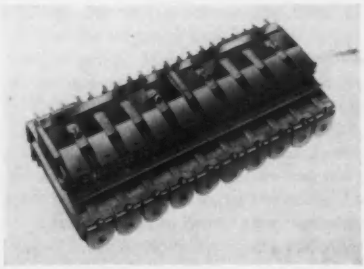
damping system employing a line contact in place of a point contact.

A multiple relay from the same company employs a common yoke integral with mounting brackets, and it is claimed that it is intended to replace telephone type relays in control circuits



Low cost, reliable

where cost is of prime importance. Contact springs of phosphor-bronze, with silver bi-metal contacts in the crossed radii technique, and automatic machine adjustment and card operation, ensure a constant contact pressure. An efficient magnetic circuit ensures that magnetic interaction between relays is virtually non-existent.

Tick **No 186** on reply card

COIL WINDING MACHINE

max. speed 3000 rev/min

A coil winding machine which operates fully automatically and does not require the services of an operator is now being manufactured by W. Aumann KG.

The machine consists of a revolving face plate to which the wire guide is fitted and of an indexing table which carries the coil jigs. Accurate layer winding is achieved by controlled movement of the face plate and can be maintained throughout the whole coil without the need for paper interleaving. Formers can be fed automatically to the jigs and ejected on completion of winding. Alternatively unsupported coils, i.e. field coils, can be wound on jigs and bonded on the machine after winding, all operations being completely automatic. The machine is fully adjustable to suit different types of coils, wire gauges, etc., and although most economical for large batch production, can be adapted for many tasks.

Maximum winding speed is 3000 rev/min. Wire gauges are from 18–45 SWG and miximum coil dimensions up to 1·2 in. in length and 8 in. diameter. The machine is usually fitted with six working stations but up to twelve can be fitted on request. A semi-automatic model is also available.

The price of the semi-automatic model complete with jigs and take-off stand is approximately £1000. The automatic machine is from £1500–£2000 depending on the type of coil.

Further details can be supplied by R. H. Cole (Overseas) Ltd.

Tick **No 187** on reply card

QUADRANT FADER

small width, novel lighting

This new twin-channel quadrant fader provides two networks within the space previously accepted as the panel cut-out required for one.

The scale on the fader is illuminated by a novel system which might well find wider application. The lighting changes colour when a predetermined position is reached in the traverse of the wiper arm, e.g. the light might change from green to red when a certain setting had been exceeded.

The unit is well constructed and easily dismantled. It is made by Electronic Components.

Tick **No 188** on reply card

QUICK LOOKS

The Polytechnic Research and Development Co.'s standing wave detector (type 219) is for the measurement of VSWR and impedance of coaxial components in the frequency range 100 to 1000 Mc/s. It is distributed in the UK by Leland Instruments Ltd.

Tick **No 189** on reply card

A compact version of the Telicator liquid flow indicator has been added to the range available from Sir W. H. Bailey & Co. Ltd., the sole agents of the manufacturers Dukes & Briggs Engineering Co. Ltd. The unit is designed for insertion in pipelines, the ends being threaded ¼, ½ or ¾ in. BSPT, and for use with liquids having temperatures up to 80°C. It can be used with high or low pressure systems and with liquids of almost any viscosity.

Tick **No 190** on reply card

The details of the latest production version of the Edwards High Vacuum Ltd vacuum fusion apparatus have been released. It is an advanced equipment for macro determination of gases in steel and other metals, and the prototype was tested by BISRA for several years.

Tick **No 191** on reply card

An alarm bell which rings on the failure of a mains supply has been produced by Londex Ltd. The bell is actuated by a clockwork mechanism.

Tick **No 192** on reply card

The pressure range of the Avica swivel pipe couplings mentioned in *New for Control* for April should have been 4000 lb/in².

INDUSTRIAL PUBLICATIONS

Four leaflets on heavy and light **rectifier equipment** from Hackbridge & Hewittic Electric Co. Ltd.

Tick **No 193** on reply card

A concise sheet on Airmec Ltd. **signal generator** (type 252).

Tick **No 194** on reply card

Informative Sperry Gyroscope brochures detailing servo valve drive amplifier, micron filter unit and electro-hydraulic servo valve.

Tick **No 195** on reply card

Loose-leaf folder from Hillman Electric Motors Ltd contains brief details of their **motors,** which range from 1/100 to ¼ h.p.

Tick **No 196** on reply card

A Fischer & Porter Ltd. booklet on **flowrator meters** embodies six graphs showing correction curves for changes in gas temperature, pressure etc.

Tick **No 197** on reply card

Details of a screwless, lugless **camblock connector** are given in a pamphlet by International Engineering Concessionaires Ltd.

Tick **No 198** on reply card

The Institution of Chemical Engineers' latest edition (Nov. 1958) of 'Regulations for the Admission of Student, Graduate and Corporate Members, and for the Examination of the Institution' is now available.

Tick **No 199** on reply card

'Terylene Saves' is the title of ICI's booklet reviewing their achievements at the Third Industrial Textiles Fair, London.

Tick **No 200** on reply card

Addison Electric Co. Ltd. list in a leaflet 13 pieces of **instrumentation equipment for cable makers.**

Tick **No 201** on reply card

From Solartron a 12-page booklet gives a useful introduction to **analogue computer** techniques and their application to the Minispace.

Tick **No 202** on reply card

Also from Solartron data sheets on the process response analyser, the pressure transducer (NT.4-317) and their digital voltmeters.

Tick **No 203** on reply card

An excellent catalogue from Kodak shows how leading industrial and commercial firms and research organizations are using **photography** in day-to-day operations.

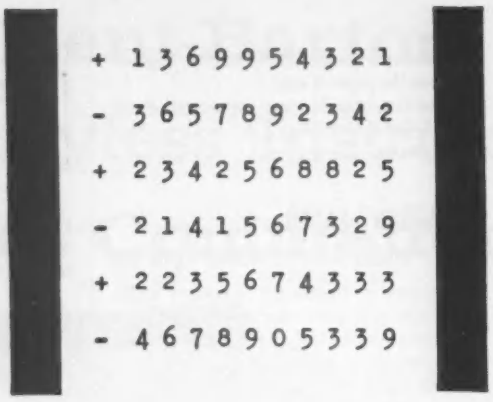
Tick **No 204** on reply card

Two other Kodak brochures describe negative materials and a new way with **colour prints.**

Tick **No 205** on reply card

A glossy brochure by Vickers-Armstrongs (Aircraft) describes the work carried out by their **nuclear engineering** section.

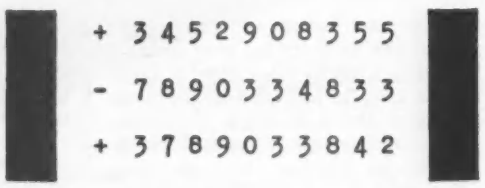
Tick **No 206** on reply card



High speed, high accuracy and reliability,

what more do you ask of

DATA LOGGING and DIGITAL DISPLAY SYSTEMS?



The Blackburn Data Monitoring and Logging equipment, which employs the latest techniques and advanced circuit design, combines high scanning speeds with both high accuracy and reliability. No mechanical part operates at the scanning speed. The data amplifier has a common mode rejection of 2×10^6: 1, with a bandwidth of DC – 1 Kc/s. Analogue to digital conversion is an all-electronic operation, the conversion being 5 milliseconds. The output, which is in decimal and binary form, may be printed and displayed remotely. The units are of robust mechanical construction and to facilitate easy maintenance all are engineered as plug-in assemblies.

BLACKBURN ELECTRONICS LIMITED

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For your bookshelf

For the mathematical

Introduction to the Design of Servomechanisms *by* **John L. Bower** *and* **Peter M. Schultesiss.** *John Wiley: New York. Chapman & Hall: London. 1958. 522 pp. £5 4s.*

Although the title proclaims the book as an 'introduction', it describes the standard techniques of servo design in more-or-less complete detail. Moreover the authors have tried to make the volume 'self-contained' so as to permit the reader to follow its teachings 'without resorting to outside references'. With this in mind, they provide no bibliography, although many references appear in footnotes. Nevertheless a selected bibliography, at least as an introduction to topics omitted from the book, would surely have been useful to the student and the practising engineer.

The authors start by defining a servomechanism, and the concepts of stability, feedback, non-linearity, etc, are introduced in Chapter 1. This is followed by chapters dealing with the classical Laplace transformations (including convolution), frequency response and minimum phase conditions, Nyquist stability criterion, root locus and statistical techniques. Other chapters deal with equalization by series networks, and performance criteria. The presence of minor loops and non-linearities is also considered.

The main text is somewhat mathematical, with few worked examples. However the problems at the end of each chapter give several interesting applications. These problems are an important contribution of the book and several of them should have appeared in the main text. Although they are supplemented by useful hints, no answers are supplied and the unsupervised student may find them difficult. The book is therefore more useful to the lecturer than the student or the practising servo engineer. P. J. BHATT

★ 231

Not for the mathematical

A Simplified Technique of Control System Engineering *by* **G. K. Tucker** *and* **D. M. Wills.** *Minneapolis-Honeywell Regulator Co. 1959. 303 pp. $5.*

The book is dedicated to the use of scientific technique in improving industrial control. The authors start at the beginning, assuming no maths beyond GCE level. This is a pity. One feels that a process control man would shy away from a book containing Nichols plots and families of transient response curves unless he had some mathematical background, and in this case he would hardly need the one page description of a sine wave. The book requires him to take every step on trust without the logic of simple mathematical analyses to help him remember the techniques.

However, it is a stimulating book, well written and illustrated, and full of information. It shows how to abstract data from dynamic analysis or empirical formulae to construct the Bode plots for the process, and how to use these to make a preliminary selection of the control modes. It then shows graphically how the response curves of the controller terms can be superimposed to forecast the optimum settings without relying on rule-of-thumb methods.

The appendices deal very thoroughly with bibliography, terminology, and also formulae for calculating the components of the Bode plots for typical processes, and the harmonic content of periodic disturbances. With this at hand as a reference, the methods are thoroughly practicable and the book will assist in intelligent design of systems, and choice of components. J. W. BUNTING

★ 232

Solutions to readers' problems?

Handbook of Automation, Computation and Control: Vol. I, Control Fundamentals *edited by* **E. M. Grabbe, S. Ramo** *and* **D. E. Wooldridge.** *John Wiley: New York. Chapman & Hall: London. 1958. 1000 pp. approx. £6 16s.*

The other volumes of this encyclopedic work deal with 'Computers and data processing' and 'Systems and components'. Each volume contains contributions from many authors. This volume is divided into Section A, General mathematics (220 pp); B, Numerical

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The range of P & G pressure gauges includes many different types to suit most applications—vacuum, combined, altitude, electric contact, differential, critical, duplex, diaphragm, capsule, etc.

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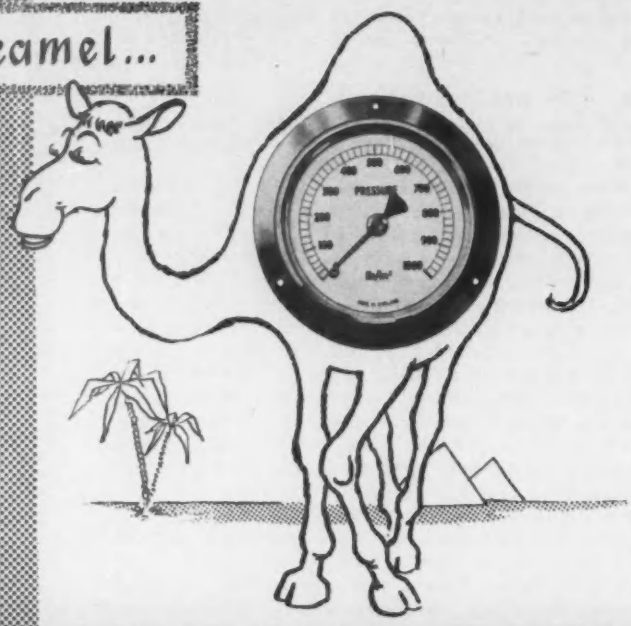

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WITH 2, 4, OR 8 POLES

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The relay when open style, is supplied with back fixing plate suitable for mounting on insulation or steel panels, or in metal cases.

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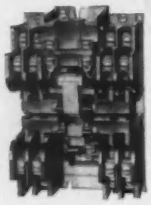
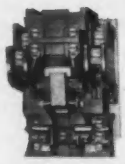
General Purpose Enclosure



8-pole Open Style
with one auxiliary
contact added.



2-pole Open Style
with two auxiliary
contacts added.

THE DONOVAN ELECTRICAL CO. LTD.

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analysis (190); C, Operations research (130); D, Information theory and transmission (110); E, Feedback control (430). The Handbook sets out to assist the 'problem solver' in the control field. This individual, of a species not previously isolated, has a graduate-level grasp of mathematics as well as engineering knowledge.

The various chapters in each section fit together neatly and the authors have achieved a uniform style. The tie-up between sections is less good; apart from Section C, which has its own language and is something of a stranger in this company, the other sections contain few cross-references though references generally are ample.

Sections A and E are those of most general interest to control engineers. A is very good—it is a handbook in itself and might justify separate publication. E comes mainly from existing textbooks and contains some direct copying that might have been avoided, since those whose librarian can afford this book are likely to have, say, Chestnut and Mayer. The treatment of 'Noise and random inputs' hardly does justice to the extent of recent work; in particular the effect of limited record length is not given the attention it deserves. In 'Nonlinear systems' a time delay is included in a list of amplitude nonlinearities!

These are minor blemishes in a well-conceived and well-executed work. The format and style are good; there are few misprints; the index is not bad. References to work outside the USA are few—almost none to the Russians. One warning: there is not much here for designers of process-control systems.

N. REAM

★ 233

Negative information

Information and Communication Practice in Industry *edited by* **T. E. R. Singer.** *Reinhold: New York. Chapman & Hall: London. 1958. 309 pp. £3 12s.*

The title of this expensively produced book is pretentious and misleading. It suggests that the book discusses communication in industry with breadth, depth and generality, whereas it is, in fact, a set of eighteen papers written by twenty-two American information officers about aspects of their particular jobs.

The papers vary widely in quality, authority and interest. The first is the longest and best; it describes the organization and functions of a modern information department. The author admits that detailed studies of the costs of information department activities are needed and suggests some lines of investigation. This paper would be of interest both to information officers and to managers concerned with the establishment of an information department.

But it is difficult to see for whom the other papers and the book as a whole are intended. There are commentaries on indexing, abstracting, editing, tabulating, illustrating, patent searching, operational research, etc. All these papers, though well-written and readable, are too short to help those who wish to learn and say nothing to those who already know.

B. C. BROOKES

★ 234

Scientific and Learned Societies of Great Britain. *George Allen and Unwin. 1958. 215 pp. £1 15s.*

The British Council has again brought a very useful book up-to-date in this third post-war edition. Rather surprisingly, it is only four pages longer than the previous edition. The Engineering and Architecture section is in fact a little shorter, mainly because the British Ceramic Society, the Royal Institution of Chartered Surveyors, and the Valuers Institution are (quite rightly) no longer considered to be engineering or architectural societies. Inevitably there are minor anomalies. For example, the British National Committee of the World Power Conference gains an entry but not the British Nuclear Energy Conference nor the British Conference on Automation and Computation. Again there may be a case on the grounds of security for excluding such famous research centres as the Admiralty Engineering Laboratory and the Royal Radar Establishment, but why include the research laboratories of the National Coal Board and not those of the Central Electricity Generating Board? In reference books, the gilt-edged rule should be 'When in doubt, insert'.

★ 235

★ Tick the revelant number on the reader imformation card for further information on any book reviewed above.

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CONTROL

BUYERS' GUIDE

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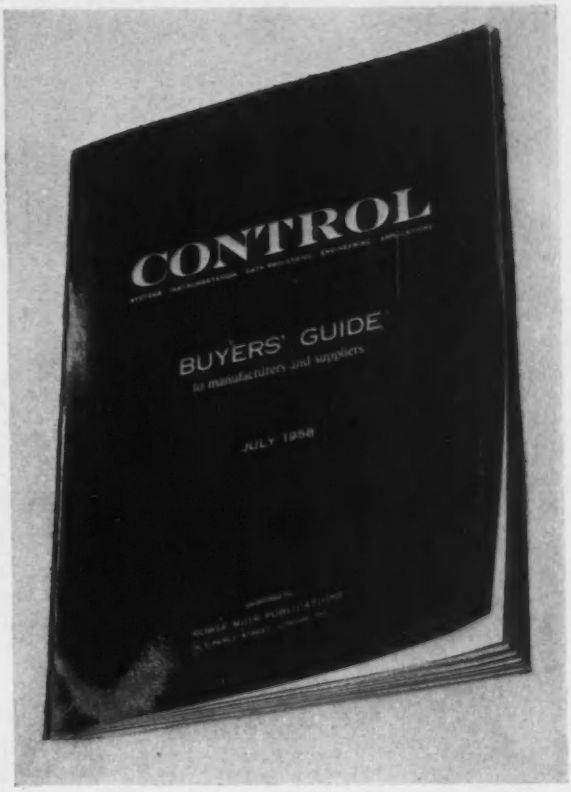

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